DESIGN OF

DIRECT CURRENT DYNAMOS.

American School of Correspondence

BOSTON, MASS.,
U. S. A.

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INSTRUCTION PAPER

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INTRODUCTION.

Having become familiar with some of the fundamental principles of the dynamo by a study of electromagnetic induction in the Instruction Paper on *Theory of Dynamo-Electric Machinery*, one is in a position to gain a more thorough understanding of the dynamo by making a more minute study of the details of actual machines. At first some of the principal types of direct current dynamos will be discussed, and then in order to bring details clearly before the mind the various parts of a complete dyuamo will be designed and the principles involved will be explained. The method of calculating used will be that adopted by Mr. A. E. Wiener, and for a more thorough study of this subject the student is referred to his book on *Dynamo-Electric Machines.* Symbols recommended by the Electrical Congress will be used together with a few others that have come into use very lately. A complete list of the notation as used throughout the Instruction Paper is also collected for easy reference. The development of this subject will also require a use of some of the absolute units which will be discussed briefly on one of the following pages.

In the design of a dynamo there must be considered, *first* the proper relation of each part of the dynamo to the whole, and *second* the relation of the electrical and magnetic circuits. No attempt can be made in this general course to give details of design for all types and all sizes of machines. Mr. Wiener's *Practical Calculation of Dynamo-Electric Machines* treats this subject very fully and very clearly, and the formulas, tables and calculations in his book are arranged for both the English and the Metric systems of measurement.

The Shunt, Series, and Compound Dynamos have already been treated briefly in the Instruction Paper on *Theory of Dynamo-Electric Machinery.* They will be still further discussed in the present paper, and their various characteristics will be treated mathematically, and again graphically by means of curves. Much of the mathematical treatment has been made *Optional.* Those wishing only a general knowledge of the subject may omit all sections so marked. Those wishing a more exact mathematical knowledge of the subject will do well to study all the sections. The mathematics will be found very simple, comprising only the applications of Ohm's law, simple arithmetic, and very elementary algebra. In discussing the design of a dynamo, first the principles are treated, and then the equations for dimensions are given. All the equations may be considered as *Optional* although the descriptive matter concerning the principles is *very important* and should be studied *very carefully.*

SYMBOLS FOR PHYSICAL QUANTITIES.

Recommended by the Committee on Notation of the Chamber of Delegates of the International Electrical Congress of 1893.

With the names added in italics of the practical magnetic units provisionally adopted by the American Institute of Electrical Engineers.

Physical Quantities.	Symbols.	Defining Equations.	Dimensions of the Physical Quantities.	Names of the C. G. S. Units.	Practical Units.
Fundamental.					
Length	L, l		L	Centimetre.	Metre.
Mass	M		M	Mass of one gramme.	Mass of a kilogramme.
Time	T, t		T	Second.	Minute ; hour.
Geometric.					
Surface	S, s	$S = L.L$	L^2	Square centimetre.	Square metre.
Volume	V	$V = L.L.L$	L^3	Cubic centimetre.	Cubic metre.
Angle	α, β	$\alpha = \frac{\text{arc}}{\text{radius}}$	A number.	Radian.	Degree ; minute ; second ; grade.
Mechanical.					
Velocity	v	$v = \frac{L}{T}$	LT^{-1}	Centimetre per second.	Metre per second.
Angular Velocity	ω	$\omega = \frac{v}{L}$	T^{-1}	Radian per second.	Revolutions (turns) per minute.
Acceleration	a	$a = \frac{v}{T}$	LT^{-2}	Centimetre per second per second.	Metre per second per second.
Force	F, f	$F = Ma$	LMT^{-2}	Dyne.	Gramme ; kilogramme.
Work	W	$W = FL$	L^2MT^{-2}	Erg.	Kilogrammetre.
Power	P	$P = \frac{W}{T}$	L^2MT^{-3}	Erg per second.	Kilogrammetre per second.
Pressure	p	$p = \frac{F}{S}$	$L^{-1}MT^{-2}$	Dyne per square centimetre.	Kilogram per square centimetre.
Moment of Inertia	K	$K = ML^2$	L^2M	Gramme-mass-centimetre-squared.	
Magnetic.					
Strength of Pole	m	$F = \frac{m^2}{L^2}$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}$		
Magnetic Moment	$\mathfrak{M}$	$\mathfrak{M} = ml$	$L^{\frac{5}{2}}M^{\frac{1}{2}}T^{-1}$		
Intensity of Magnetization	$\mathfrak{I}$	$\mathfrak{I} = \frac{\mathfrak{M}}{V}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$		
Field Intensity	$\mathfrak{H}$	$\mathfrak{H} = \frac{F}{m}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gauss.*	*Gauss.*
Flux of (Magnetic) Force	Φ	$\Phi = \mathfrak{H}S$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}$	*Weber.*	*Weber.*
Magnetic Induction	$\mathfrak{B}$	$\mathfrak{B} = \mu\mathfrak{H}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gauss.*	*Gauss.*
Magnetizing Force‡	$\mathfrak{H}$	$\mathfrak{H} = \frac{4\pi NI}{L}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gauss.*	*Gauss.*
Magnetomotive Force	$\mathfrak{F}$	$\mathfrak{F} = 4\pi NI$	$L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gilbert.*	*Gilbert;* 1 *Gilbert*=0.7958 ampère-turns (a–t).
Reluctance (Magnetic Resistance)	$\mathfrak{R}$	$\mathfrak{R} = \nu\frac{L}{S}$	L^{-1}	*Oersted.*	*Oersted.*
(Magnetic) Permeability	μ	$\mu = \frac{\mathfrak{B}}{\mathfrak{H}}$	A number.		
(Magnetic) Susceptibility	κ	$\kappa = \frac{\mathfrak{I}}{\mathfrak{H}}$	A number.		
Reluctivity (Specific Magnetic Resistance)	ν	$\nu = \frac{1}{\mu}$	A number.		
Electromagnetic.					
Resistance	R, r	$R = \frac{E}{I}$	LT^{-1}	....	Ohm.
Electromotive Force	E, e	$E = RI$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-2}$	....	Volt.
Difference of Potential	U, u	$U = RI$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-2}$	....	Volt.
Intensity of Current	I, i	$I = \frac{E}{R}$	$L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	....	Ampère.
Quantity of Electricity	Q, q	$Q = IT$	$L^{\frac{1}{2}}M^{\frac{1}{2}}$	....	Coulomb ; ampère-hour
Capacity	C, c	$C = \frac{Q}{E}$	$L^{-1}T^2$	....	Farad.
Electric Energy	W	$W = EIT$	L^2MT^{-2}	....	Joule ; watt-hour.
Electric Power	P	$P = EI$	L^2MT^{-3}	....	Watt ; kilowatt.
Resistivity (Specific Resistance)	ρ	$\rho = \frac{RS}{L}$	L^2T^{-1}	....	Ohm-centimetre.
Conductance	G, g	$G = \frac{1}{R}$	$L^{-1}T$	....	Mho.
Conductivity (Specific Conductance)	γ	$\gamma = \frac{1}{\rho}$	$L^{-2}T$		
Coefficient of Induction (Inductance)	L, l	$L = \frac{\Phi}{I}$	L	....	Henry.

‡ N Is the number of windings, and L the length of the solenoid generating the magnetizing force.

DESIGN OF

DIRECT CURRENT DYNAMOS.

In the study of **Direct Current Dynamos** it will be of advantage to divide the subject into two parts ; (1) Constant Potential Dynamos, machines that supply current at a constant pressure for all loads ; and (2) Constant Current Dynamos, machines that supply a current of constant strength for all loads.

It has been explained how the energy in a circuit is equal to the product of the difference of potential, E, between the terminals of the dynamo, and the current, I, flowing in the circuit, or $E\,I$. When this product $E\,I$ is large, a large amount of work is expended in the circuit, and to express this fact it is said that a heavy load has been put upon the dynamo. The value of $E\,I$ is increased by increasing either E or I, or both, that is, the load on the dynamo is increased when a larger current comes from it, or when the same current flows but at a higher voltage.

By having more lamps or running more motors on the circuit we increase $E\,I$, or the load upon the dynamo. In constant potential machines, E remains constant for any change in the number of lamps or motors on the circuit, within the limits of the capacity of the machine, hence to increase the load on the dynamo, I must be increased, and it is seen readily enough that the load is proportional to I if E remains constant, or since I is inversely proportional to R, the resistance of the circuit, the load on a constant potential machine is inversely proportional to the resistance of the circuit.

In a constant current machine I is constant and E must be increased if $E\,I$, the load, is to increase. If E rises, and I remains the same, then R must increase according to Ohm's law. Hence the load on a constant current machine is proportional to E and to R. An increased load on constant current machines, requires larger values of E and R; on constant potential machines it requires a larger value of I and a smaller value of R.

If E is to remain constant the magnetization produced by the field coils must remain constant, or in other words the conductors on the armature must cut the same number of magnetic lines of force each second. If I is to remain constant and E is to increase then a correspondingly greater number of lines of force must be cut each second.

The essential difference between the two types of machines then is that in one there is a nearly constant magnetic flux for all loads, and in the other there is a magnetic flux varying with the load. The two types of constant potential and constant current dynamos will be considered separately.

Constant Potential Dynamos.

For supplying incandescent lamps in parallel, or for running motors to furnish power at a constant speed, a constant electromotive force is required at the terminals of the lamps or at the brushes of the motor. As the number of lamps in multiple is increased, or as more load is thrown on the motors, or as more motors are started, there are more paths prepared for the current in the outside circuit, and more current flows from the dynamo. The voltage remains constant, and the resistance of the circuit being less, the current becomes greater.

It has been pointed out, however, (Inst. Paper on *Theory of Dynamo-Electric Machinery*, pp. 35–36) that on account of the armature resistance the lost voltage in the armature increases with the load, and in addition to this an increase of load increases the armature cross magnetizing effect which tends to weaken the field and therefore to still further decrease the voltage. Therefore if the speed of the shunt dynamo is not altered, an increase of load will decrease the effective voltage by the amount of increase in the lost voltage, and by the amount of decrease in the field strength. The result will be to make the lamps burn less brightly for every extra one put on the circuit, or in the case of a power circuit the motors would slow down a few revolutions each time the load on the dynamo was increased.

As the electromotive force of a dynamo is directly proportional to the speed, to the number of armature conductors, and to the magnetic flux due to the field coils, so it may be changed in

value by changing the value of any one of these factors. Although it is possible to change the effective value of the number of conductors on the armature by means of a change in the position of the brushes, and although it is possible to change the speed of the machine by means of gearing, yet neither of these methods are convenient, nor do they prove very satisfactory. It is possible, however, to change the value of the magnetic flux produced by the field coils quite easily and to regulate the value of this change quite accurately.

Suppose that the number of ampere-turns needed for a given

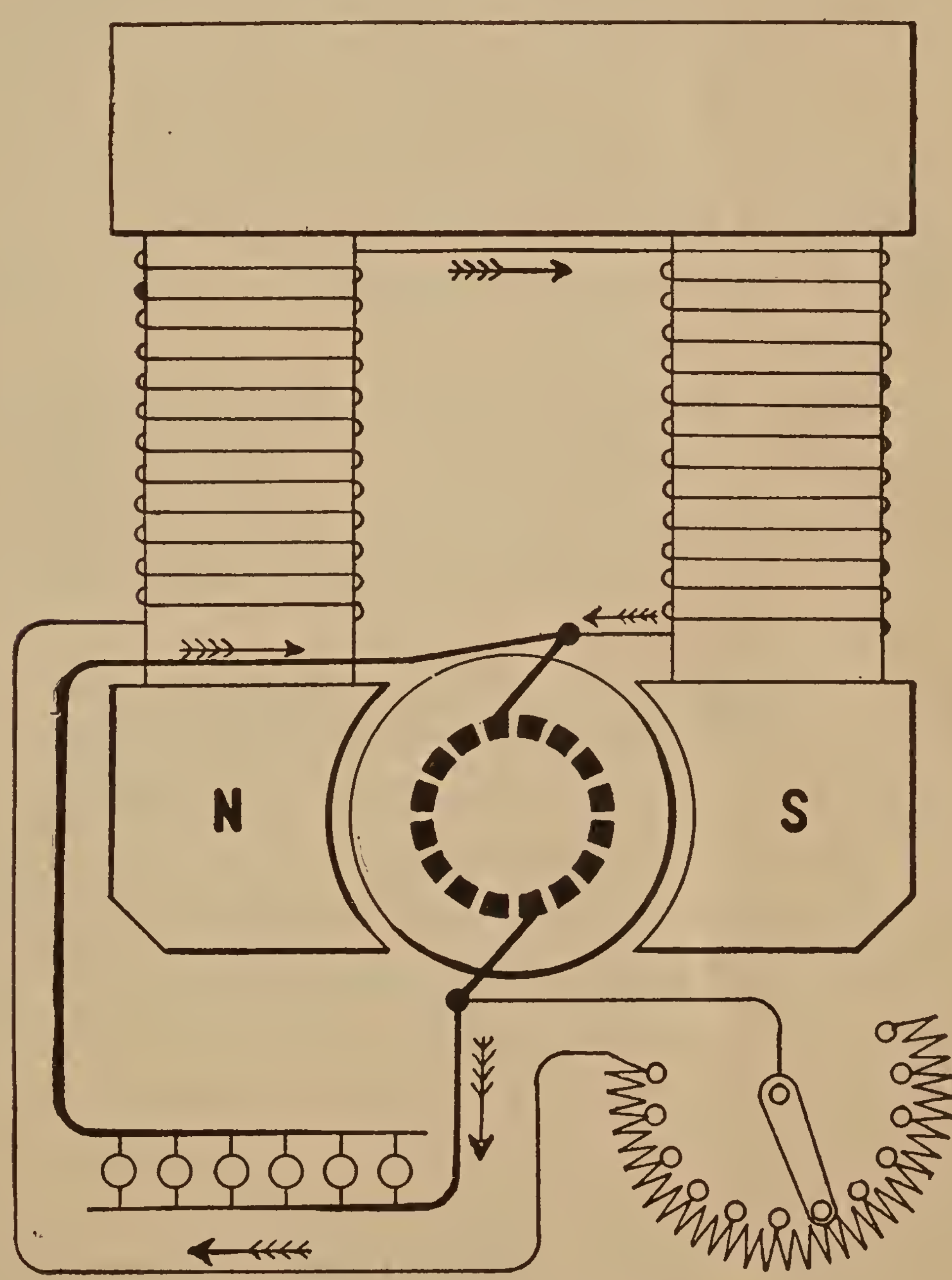

Fig. 1. Dynamo and Rheostat.

machine has been determined (the method for doing this will be explained later) and suppose that it has been decided what proportion of the ampere-turns shall be in amperes and what propor-

tion in turns so that the size of the wire is fixed. Then if a somewhat larger wire than the one required be used the resistance of the field coils will be less and the field current larger than it was figured. By inserting a **rheostat**, or resistance which can be varied at will, between the field coil and one of the brushes, the current in the coil can be cut down to the proper value under normal conditions, and when the load increases and the effective voltage tends to drop, it is only necessary to cut out some of the resistance in the rheostat to obtain more current, and consequently greater excitation in the field coil, thereby raising the voltage to its normal value again. The rheostat (see Fig. 1) consists generally of a resistance with connections at short intervals along it and terminating in metal contacts arranged in a circle. A sliding contact piece is moved over them by the handle, introducing the current at any point on which the sliding contact is resting. In this way the amount of resistance in series with the field coil may be regulated with great exactness.

This regulation is generally effected by hand, the resistance being decreased when the voltmeter shows that the voltage is falling on the line and vice versa. By means of regulators, magnets, solenoids and various electrical and mechanical means this regulation is sometimes made automatic.

Efficiency of Dynamos.

No machine has ever yet been built so perfect that it is able to apply to the work for which it was built all the energy which it receives. Some of it is used up in keeping the machine itself running ; this is called waste energy, and goes to overcome friction of some kind. The more efficient the machine the less is the waste energy. This waste is undesirable for two reasons, first because it deducts something from the output of the machine, and second because though wasted it is not lost, and reappears as heat. Every one is familiar with the effects of a hot box. The energy going to waste to overcome friction in the journal is converted into heat and raises the temperature of the parts. If the heat is not carried off by oil the parts may enlarge slightly which in turn causes more friction, more and more power is absorbed, and the machine rendered more and more inefficient until it may even stop entirely,

the energy supply being insufficient to overcome the friction; the efficiency is then zero.

Efficiency is usually expressed in terms of the energy delivered to the machine and is given as the relative percentage that the output is of the input. Modern commercial dynamo machines of fair size reach an efficiency as high as 92%, that is they deliver at their brushes electrical energy equal to $\frac{92}{100}$ of the mechanical energy furnished them at the pulley.

Part of the wasted energy is used in overcoming mechanical friction in bearings and brushes, most of this being in the bearings. This should not exceed 5% and in many cases is much less, depending on the size, design and purpose of the generator. The remainder of the energy is accounted for in the electrical losses, for although, as previously explained, the energy is not lost since it reappears as heat, it is of course lost from the practical standpoint. The resistance of wire to the passage of an electrical current is analogous to mechanical friction. It requires power to force a current through a wire although it need only be a very small portion of the total power that can be transmitted by the current. The evidence of the waste of power appears in the loss of voltage which takes place between the beginning and end of the wire and this power reappears as heat in the wire. Evidently therefore there must be a loss in the windings of the dynamo due to the current circulating in them, and this loss is usually considered under the heads of armature loss and field loss. By making the wire large and therefore reducing the resistance, this loss may be reduced to as small a value as desired, the limit being found in expense and practicability of construction.

There is another electrical loss termed core loss which results from that property of iron which has already been dealt with under the name of hysteresis. This is also a kind of friction and the power expended in overcoming it reappears as heat in the iron core. (See page 25 Instruction Paper on *Theory of Dynamo-Electric Machinery.*) Hysteresis is increased by hardness in the metal and increase of rapidity in the changes of magnetism to which it is subjected. For this reason the softest possible iron or steel is selected for armatures since they are subjected to one reversal of magnetism for every revolution they make. There is a very

small additional loss due to **eddy currents.** This is the result of setting up currents which are not useful or desirable in metallic parts of the machine. This effect is very successfully avoided by laminating the armature core, which consists in building it up of thin sheets of iron whose planes are at right angles to the conductors. The faces of the laminations are coated with varnish, or have paper between them, or are allowed to rust, so as to be coated with an iron oxide, which effectually stops any currents which tend to generate in the iron mass parallel to the conductors. The core losses and eddy current losses together should not exceed 2%.

The **shunt-wound dynamo** has high resistance field coils or many turns of fine wire. As the terminals of the field coils as well as the terminals of the outside circuit are both connected to the brushes there are two paths through which the current may

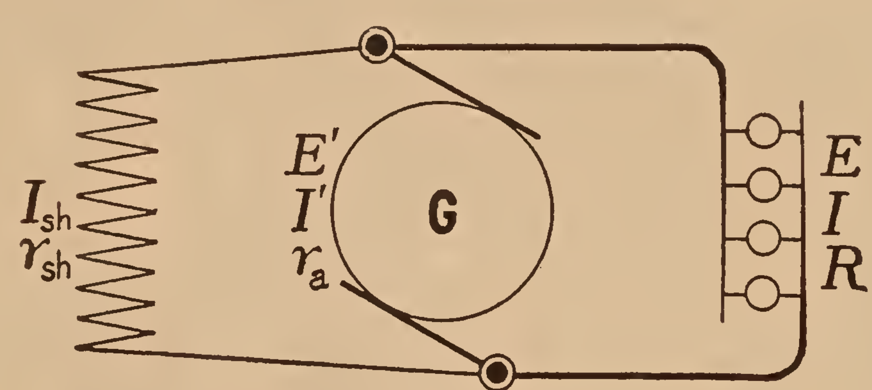

Fig. 2. Diagram of Shunt-Wound Dynamo.

flow (see Fig. 2). The path leading to the outside circuit where the commercial results are accomplished is considered the circuit of first importance and the path through the field coils, which however is important to the proper working of the dynamo, is termed a shunt around the other path.

The important formulas showing the characteristics of the shunt dynamo will be developed.

Let I' = total current in armature;
I_{sh} = current flowing in shunt coils;
I = useful current flowing in outside circuit;
E' = total E. M. F. generated in armature;
E = potential of dynamo, both for shunt coil, and outside circuit;
r_a = resistance of armature;
r_{sh} = resistance of shunt field coils;
R = resistance of outside or useful circuit;
η_e = electrical efficiency.

These various quantities can be expressed in terms of each other in a number of different ways. This is of value in studying and understanding the characteristics of the shunt dynamo, and in finding the values of unknown terms when others are known. It is obvious by looking at diagram of Fig. 2, that the total current is the sum of the outside current and shunt current, or

$$I' = I + I_{sh} \quad \text{or} \quad I' = I + \frac{E}{r_{sh}}$$

This latter equation shows what amount of the armature current is lost in the shunt field. Also the total current in the armature is equal to the total E. M. F. divided by the total resistance.

$$I' = \frac{E'}{r_a + \dfrac{R \times r_{sh}}{R + r_{sh}}}$$

for the joint resistance of the shunt and outside circuits (See Instruction Paper on the *Electric Current*, p. 17) is equal to the product of the two divided by the sum of the two.

*The relation can be expressed in still another way since

$$\frac{E}{R} = I \text{ and } \frac{I}{I_{sh}} = \frac{r_{sh}}{R} \text{ from which } I' = \frac{E}{R}\left\{1 + \frac{R}{r_{sh}}\right\}$$

E, R, and r_{sh} are often known quantities from which I' and E' may be found by the aid of these relations. The value of the useful current in the outside circuit is

$$I = \frac{E}{R}$$

and the value of the current in the shunt current is

$$I_{sh} = \frac{E}{r_{sh}}$$

†The value of the total E. M. F. generated by the dynamo is

$$E' = E + I' r_a$$

from which it may be seen by inspection that the lost volts in the armature $E' - E$, increase directly with I'. If E' and r_a are considered as remaining constant, then an increase in I' increases $I'r_a$ also, and E must become less. If E is decreased and E' is

* Optional. † Study.

constant then their difference which is equal to the lost volts in the armature must increase.

*As $I' = I + I_{sh}$, we have by multiplying by r_a and substituting for $I' r_a$ its value $E' - E$,

$$E' = E + I r_a + I_{sh}\, r_a = E + \frac{E}{R}\, r_a + \frac{E}{r_{sh}}\, r_a$$

$$= E \left\{ 1 + \frac{r_a}{R} + \frac{r_a}{r_{sh}} \right\} = E \times r_a \left\{ \frac{1}{r_a} + \frac{1}{R} + \frac{1}{r_{sh}} \right\}$$

†The **electrical efficiency** of the dynamo is equal to the value of the useful energy divided by the total energy developed in the armature, the total energy itself being equal to the useful energy plus the energy lost in the armature, plus the energy lost in the field coils. Therefore the electrical efficiency is

$$\eta_e = \frac{E\,I}{E'\,I'} = \frac{I^2\,R}{I^2\,R + I'^2\,r_a + I^2{}_{sh}\,r_{sh}}$$

*As $I' = I \times \dfrac{R + r_{sh}}{r_{sh}}$, and $I_{sh} = \dfrac{I\,R}{r_{sh}}$ we obtain

$$\eta_e = \frac{I^2\,R}{I^2\,R + \left\{ I \times \dfrac{R + r_{sh}}{r_{sh}} \right\}^2 r_a + \left\{ \dfrac{I\,R}{r_{sh}} \right\}^2 r_{sh}}$$

$$\eta_e = \frac{I^2\,R}{I^2\,R + \left\{ \dfrac{I^2\,R^2 + 2\,I^2\,R\,r_{sh} + I^2\,r^2{}_{sh}}{r^2{}_{sh}} \right\} r_a + \dfrac{I^2\,R^2}{r_{sh}}}$$

$$\dagger = \frac{1}{1 + 2\,\dfrac{r_a}{r_{sh}} + \dfrac{r_a}{R} + \dfrac{(r_a + r_{sh})\,R}{r^2{}_{sh}}}$$

By a mathematical analysis it can be proven that the value of η_e is a maximum when

$$R = r_{sh} \sqrt{\frac{r_a}{r_a + r_{sh}}}$$

This equation shows what the resistance of the outside circuit of a dynamo should be, knowing the shunt and armature resistances, in order to have the machine carry the proper load for maximum electrical efficiency.

*Replacing R by its value in terms of r_a and r_{sh} we have the terms

$$\frac{R\,(r_{sh}+r_a)}{r^2{}_{sh}} = \frac{r_{sh}+r_a}{r_{sh}}\sqrt{\frac{r_a}{r_a+r_{sh}}} = \frac{\sqrt{r_a\,(r_{sh}+r_a)}}{r_{sh}}$$

$$\text{and } \frac{r_a}{R} = \frac{r_a}{r_{sh}}\sqrt{\frac{r_a+r_{sh}}{r_a}} = \frac{\sqrt{r_a\,(r_a+r_{sh})}}{r_{sh}}$$

† The equation of the maximum efficiency of a shunt dynamo becomes

$$\eta_{e.Max.} = \frac{1}{1+2\,\dfrac{\sqrt{r_a\,(r_a+r_{sh})}}{r_{sh}}+2\,\dfrac{r_a}{r_{sh}}}$$

The value of the armature resistance compared with the value of the shunt resistance is always so small that $r_a + r_{sh}$ may be written r_{sh} without any appreciable error and the value of $\frac{r_a}{r_{sh}}$ is so small that it may be neglected, then the approximate value of the electrical efficiency of the shunt dynamo may be written in very simple terms and may be considered as equal to

$$\eta_e = \frac{1}{1+2\sqrt{\dfrac{r_a}{r_{sh}}}}$$

and the approximate ratio of the shunt resistance to the armature resistance is expressed by the formula

$$\frac{r_{sh}}{r_a} = \left\{\frac{2\,\eta_e}{1-\eta_e}\right\}^2$$

The following table from Wiener gives the necessary ratios of the resistance of the shunt field to the resistance of the armature for various electrical efficiencies for shunt dynamos. As these values are not given in ohms but only as ratios they hold good for all shunt dynamos, large or small. It will be noted that this electrical efficiency may be as near 100% as is desired, from a theoretical standpoint, but the limit is generally governed by the practical consideration of the cost. If the armature resistance is made too small, more copper is used to carry the current than is required, and if the field coil resistance is made extremely high the wire will be very small and very expensive.

TABLE GIVING RATIO OF SHUNT TO ARMATURE RESISTANCE FOR VARIOUS ELECTRICAL EFFICIENCIES FOR SHUNT DYNAMOS.

Electrical Efficiency.	Ratio of Shunt to Armature Resistance.	Electrical Efficiency.	Ratio of Shunt to Armature Resistance.
$100 \times \eta_e$	$\frac{r_{sh}}{r_a}$	$100 \times \eta_e$	$\frac{r_{sh}}{r_a}$
80%	64	96	2,304
85	128	97	4,182
90	324	98	9,604
93	706	99	39,204
95	1,444	99.5	158,404

A number of very important characteristics of a dynamo obtained from experiment may be shown by means of what are called **Characteristic Curves.** These same characteristics may generally be figured out mathematically but it is more correct and more satisfactory to get at the results from a practical test as a general rule. These characteristic curves explain the actions and possibilities of a dynamo in very much the same way that the indicator card of a steam engine gives its desired information. By drawing the characteristic curves to some known scale the horse-power at which the dynamo will work with the greatest efficiency can be calculated.

A **Saturation Curve** shows to what degree the iron has been saturated with magnetism and thus whether or not it is properly designed and proportioned as regards its magnetic circuit. Fig. 3 shows such a curve. The curves are formed by plotting points whose abscissae are values of ampere-turns and whose ordinates are the corresponding values of the voltage, these points being plotted for varying values of the current. The readings may be observed for both ascending and descending values of the current thus showing the effects of hysteresis. By means of two electro-magnets, one being placed in series in the circuit so as to pull in proportion to the current, and the other being a shunt so as to pull with a force proportional to the voltage, it is possible to cause a dynamo to draw its own characteristic curve just as a steam engine draws its own indicator card.

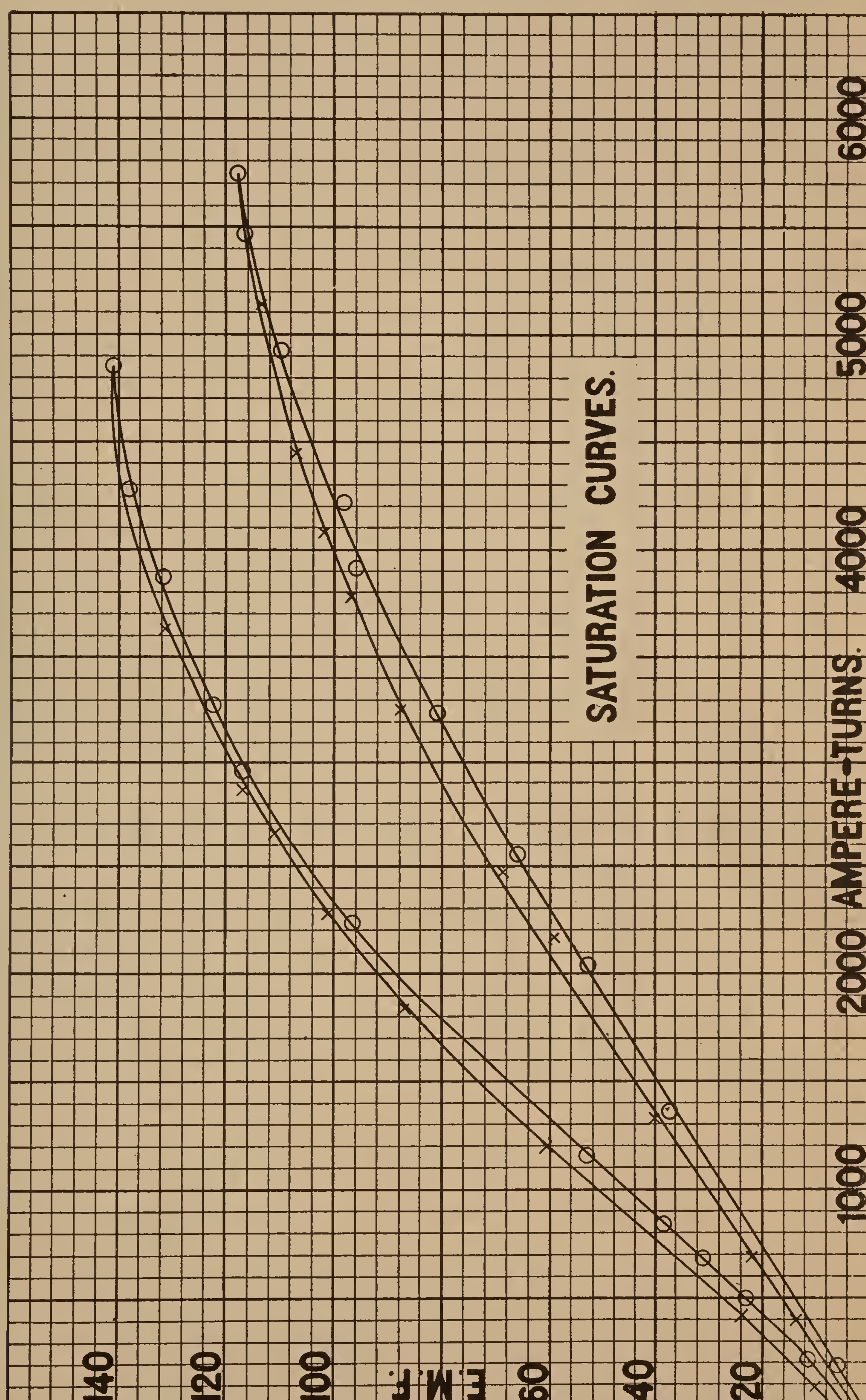
SATURATION CURVES.
AMPERE-TURNS.
E.M.F.
1000
2000
4000
5000
6000
20
40
60
100
120
140

Fig. 3.

Having drawn the characteristic curve of a machine to some particular scale, and knowing either the current, I, or voltage, E, at which the dynamo is working, the other value may be read off the curve directly. The value of the current multiplied by the corresponding voltage gives the output of the machine in watts and this divided by 746, the number of watts corresponding to one horse-power, gives the output of the machine in mechanical units or in horse-power.

It is possible to plot horse-power curves on the same paper with the characteristic curve (see Fig. 4) since horse-power = $\frac{\text{volts} \times \text{amperes}}{746}$. Any combination of amperes $\times$ volts which will give 746 is equal to one horse-power, thus 7.46 amp. $\times$ 10 volts = 1 horse-power. Evidently then there is an infinite number of points the product of whose co-ordinates equals 746, and a line drawn through these points is a curve of one horse-power. If the characteristic of the dynamo cuts the curve at any point it means that at that point the dynamo is furnishing one horse-power of electrical energy. It follows at once that curves may be similarly drawn for 2, 3, 4, or any number of horse-power. Then a glance at the characteristic curve will reveal at once what the activity of the dynamo is.

The dynamo has two characteristic curves, the **External Characteristic** found by plotting the voltage and the current of the outside circuit and the **Internal Characteristic** found by plotting the total voltage and the total current generated. The characteristic due to series coils is similar to a curve of magnetic induction, the value of the voltage increasing rapidly at first with the increase of the ampere-turns; then as the iron core becomes more or less saturated with magnetic lines the voltage increases more slowly as the ampere-turns or current increase. The shunt characteristic, however, has a maximum value of voltage (see Fig. 4) when the external current is zero and falls as the current increases, due partly to the demagnetizing effects of the armature and partly on account of the ever increasing lost volts in the armature which increase with the current. At first the voltage falls as the current or load increases but finally the capacity of the dynamo is reached and after a certain fixed point both voltage and current decrease and fall to zero very rapidly, as shown in the figure.

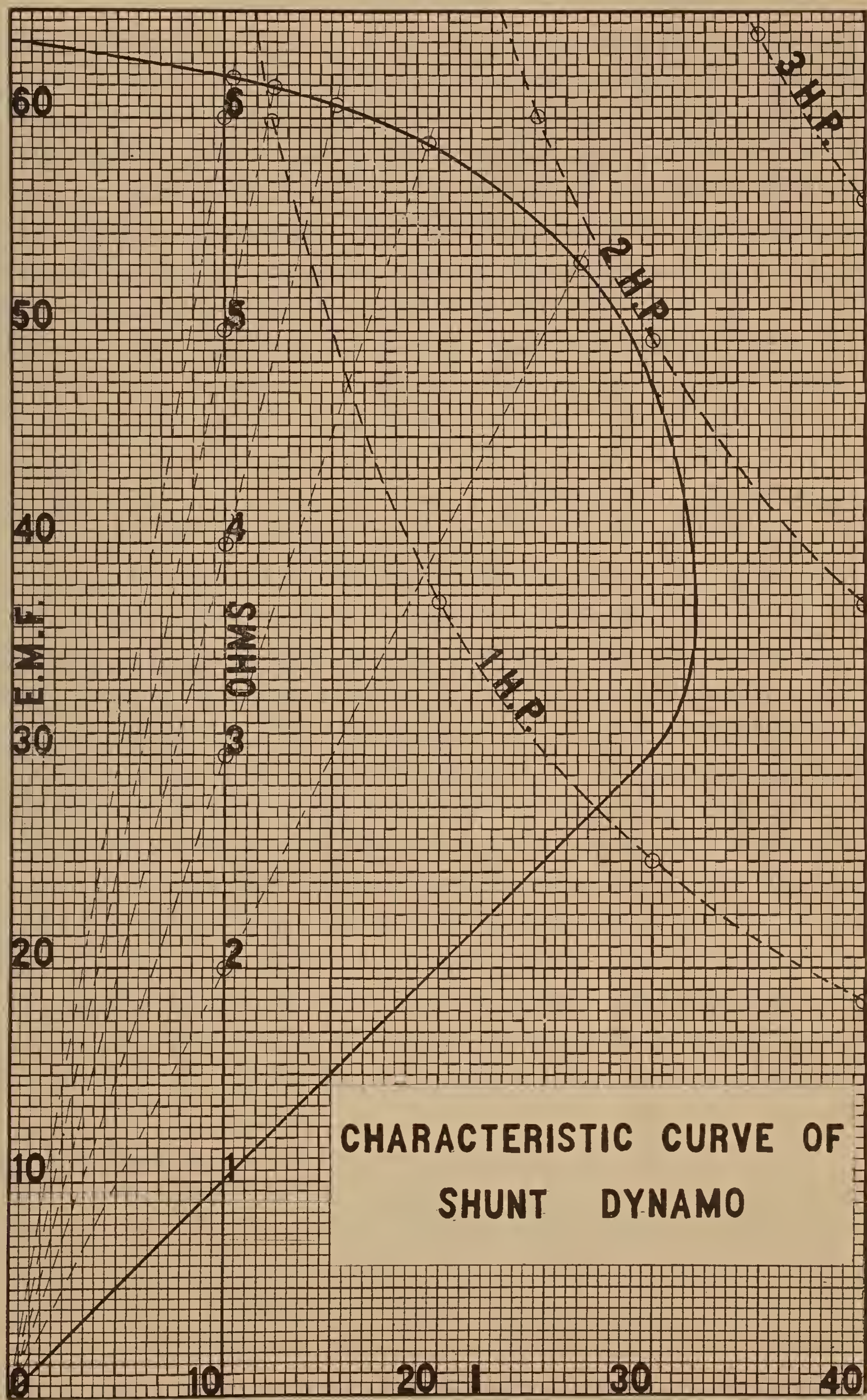
60
50
40
E.M.F.
30
20
10
0
6
5
4
OHMS
3
2
1
10
20
I
30
40
3 H.P.
2 H.P.
1 H.P.
CHARACTERISTIC CURVE OF
SHUNT DYNAMO

Fig. 4.

The resistance of the outside circuit corresponding to any point on the characteristic curve can be found very readily. The voltage divided by the current gives the resistance. By drawing a straight line (see Fig. 4) from the origin or the point where the current and voltage are 0 through the point corresponding to 20 volts and 10 amperes it will intersect the characteristic curve at a certain point. It is obvious from the figure that the voltage at this point is just double the current and so the resistance here is 2 ohms. Similarly by drawing a line from the origin through the point where voltage is 40 and current 10 the characteristic curve is intersected at another point and the resistance of the circuit at this point is 4 ohms. A scale of resistance may be marked on the vertical line corresponding to 10 amperes. By drawing a line from any point on the characteristic curve to 0, the point of intersection on this resistance scale line gives the resistance of the outside circuit. The characteristic curve shown in Fig. 4 is for a small shunt dynamo which being run at 630 revolutions gave a maximum of a little less than 2 horse-power at 47.5 volts and 30 amperes. With a decrease in resistance much below 2 ohms the current increases but little, whereas the voltage falls a great deal. If the external resistance becomes less than 1 ohm the machine loses its voltage and current immediately and will not build itself up again until the resistance is increased. The most critical part of this curve is where the voltage is about 30 or 31 and any given change of resistance at this point will alter the voltage more than at any other part of the curve. By increasing the resistance the voltage is steadily increased until it gets to its maximum when the external circuit is open and the resistance is infinite, the whole voltage being then available for magnetizing the shunt field coils to their maximum strength.

Fig. 5 shows the characteristic curves of a shunt-wound Gramme dynamo capable of giving 400 amperes at 120 volts. The armature conductors were not capable of carrying more than 400 amperes, and the part of the curves not actually found by experiment is shown in dotted lines. The lower curve marked E is the external characteristic while the upper curve marked E' is formed from it by adding to the external voltage at any point the corresponding value of the voltage lost in the armature at the given time.

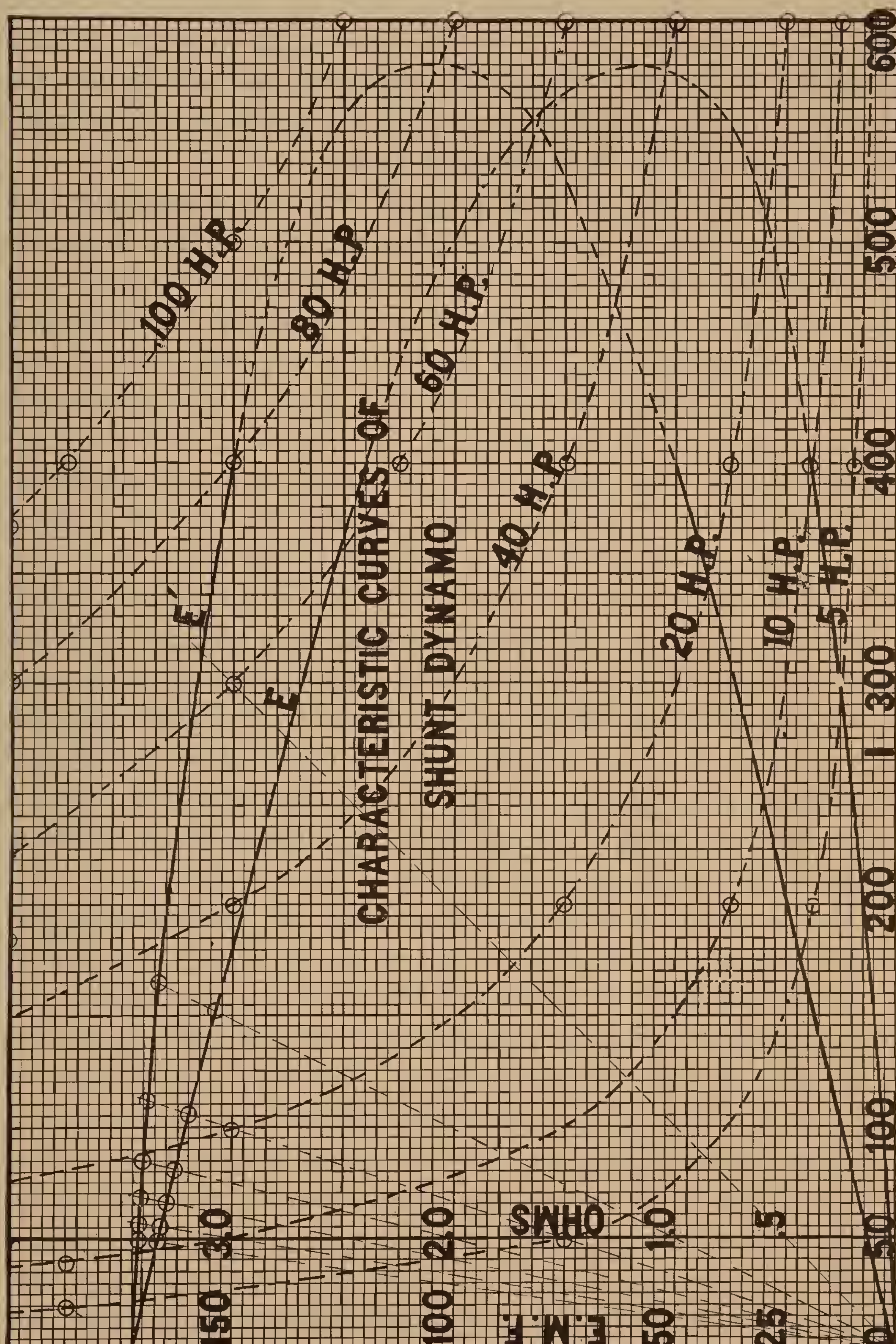

Fig. 5. Characteristic Curves of Shunt-Wound Gramme Dynamo.

In order to have the magnetic circuit of a dynamo properly proportioned and dimensioned for the magnetic flux which it is to carry it is necessary, first, to find the necessary number of lines required to be cut by the armature conductors in order to produce the desired voltage, and then to provide a magnetic circuit of sufficient cross section for these magnetic lines.

After a machine has been designed and built a **magnetic saturation curve** may be taken to test the condition of the magnetic circuit as regards saturation. This tests the accuracy of the calculations, and serves as a check. From an economical standpoint it is best not to carry the magnetic flux too near the point of saturation during normal working, for the number of ampere-turns required to produce a given magnetic flux is greater in a saturated field than in one not saturated. In certain types of machines, however, there are certain advantages in practical points of working and regulation to be derived from having saturated fields that are of such importance as to outweigh the value of greater efficiency. By knowing from the type and the design of a machine to what degree its fields should be saturated, and by having an experimental saturation curve of the machine, a comparison can be made between the ideal and the result. Fig. 3 gives the saturation curve of the magnetic circuit of a Crocker-Wheeler dynamo for no load and with load, the dynamo running at a constant speed of 1,620 revolutions per minute.

For a given field magnetizing force in ampere-turns the dynamo will show considerable difference in voltage between a run with load and one without. This shows quite plainly the effect of the lost voltage in the armature and also the loss due to the armature demagnetizing tendency. The values of voltage at the terminal of the machine were observed both for increasing and decreasing values of magnetizing current or ampere-turns. The result is shown in the double curves (see Fig. 3) and is caused by the phenomenon of hysteresis. The magnetism of the dynamo lags behind the increasing magnetizing force and so appears too low, and again it lags behind the decreasing magnetizing force and appears too high.

The Internal and External Shunt Characteristic Curves of a Crocker-Wheeler dynamo are shown in Fig. 6. This machine is

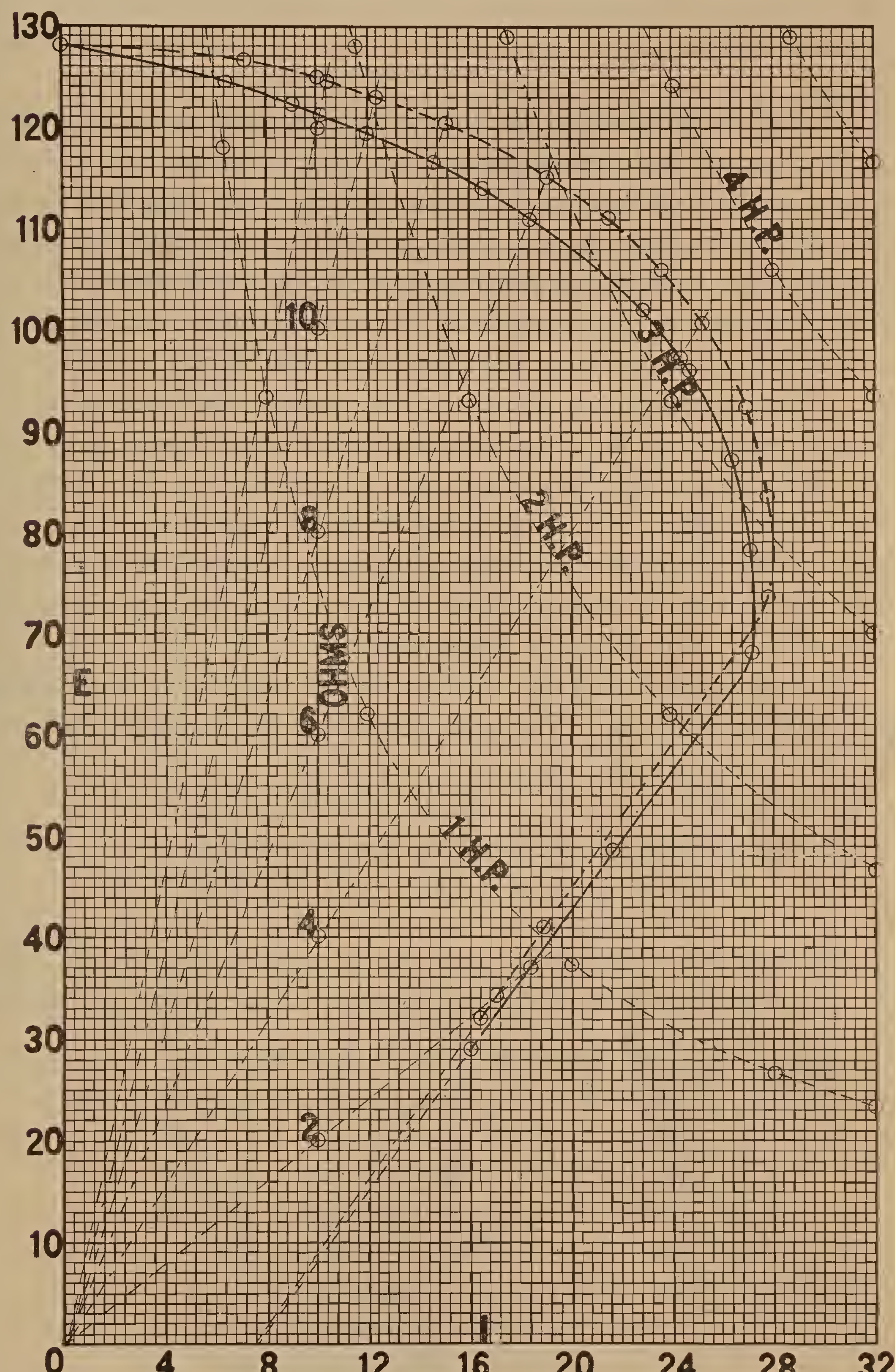

Fig. 6. Internal and External Shunt Characteristic Curves.

really a compound dynamo, and in order to get shunt characteristic curves, the series coils were simply disconnected and the terminals of the outside circuit were connected directly with the brushes.

It will be noted from the figure that the voltage drops gradually at first as the load increases and that it drops much more rapidly as the load reaches a maximum. By comparing this figure with Fig. 11 which shows characteristic curves for the same machine run as a compound dynamo, it will be noted that the maximum load of the shunt machine is quite a little less than the maximum load of the same machine when the series coils are in use. The magnetizing effect of the series coils increases in strength practically in proportion as the load increases and so the series coils play a very important part in maintaining the strength of the field coils. It will be noted that the maximum energy as shown in the shunt characteristic curve is not quite $3\frac{1}{2}$ horse-power, while the maximum energy shown in the compound characteristic curve of Fig. 11 is nearly 8 horse-power.

The speed at which the shunt characteristic curve was taken was 1,500 revolutions. The total current of the armature is

$$I' = I + I_{sh} = I + \frac{E}{r_{sh}}.$$

The total voltage generated by the armature is,

$$E' = E + \left\{ I + \frac{E}{r_{sh}} \right\} r_a.$$

In the series-wound dynamo, there is but one circuit (see Fig. 7), and therefore but one current, I, the value of which

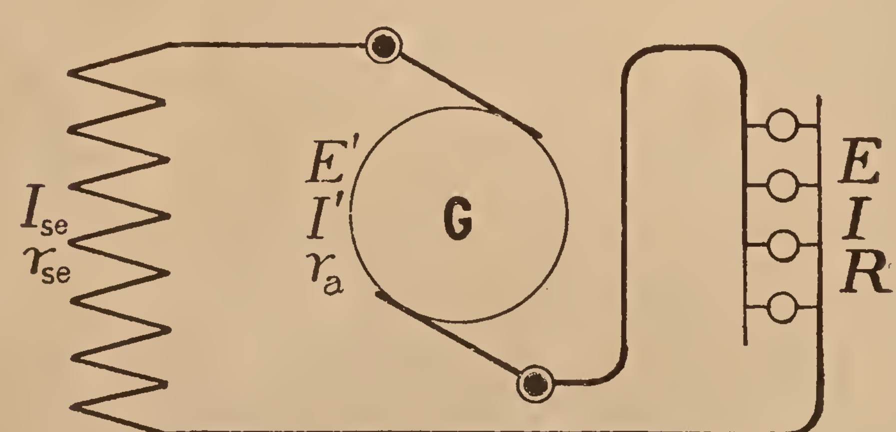

Fig. 7. Diagram of Series-Wound Dynamo.

depends upon the value of the total voltage E' and the total resistance which is made up of r_a, r_{se} and R. The series field is com-

posed of a comparatively few turns of heavy copper conductor and is connected in series with the armature and the external circuit.

The current may be expressed as

$$I' = I_{se} = I$$

$$I' = \frac{E'}{R + r_a + r_{se}}$$

$$* I = \frac{E + (E' - E)}{R + (r_a + r_{se})} = \frac{E}{R} = I'$$

$$I_{se} = \frac{E' - E}{r_{se}} = I = I'$$

The total voltage may be expressed as

$$E' = E + I\,(r_a + r_{se}) = E \left\{ 1 + \frac{r_a + r_{se}}{R} \right\}$$

† The electrical efficiency is

$$\eta_e = \frac{\text{useful energy}}{\text{total energy}} = \frac{E\,I}{E'\,I'} = \frac{E}{E'}$$

or in terms of resistances it may be expressed as

$$\eta_e = \frac{I^2\,R}{I'^2\,(R + r_a + r_{se})} = \frac{R}{R + r_a + r_{se}}$$

From the equation $I' = \frac{E'}{R + r_a + r_{se}}$ it is seen that an increase in the outside resistance diminishes the current in the field coils, thus diminishing the magnetic flux. As the constancy of the magnetic flux depends upon the constancy of the current value these series-wound dynamos are best adapted to give a constant current, and are used mostly for running arc lamps on series circuits.

From the equation $E' = E + I\,(r_a + r_{se})$ it is seen that the total current in the armature is the same as the current in the outside circuit, also that the total voltage is the external voltage plus the lost voltage in the armature and series coils due to the passage of the current.

From the equation for electrical efficiency it is evident that it will be a maximum when the armature resistance and series coil resistance are as small as possible.

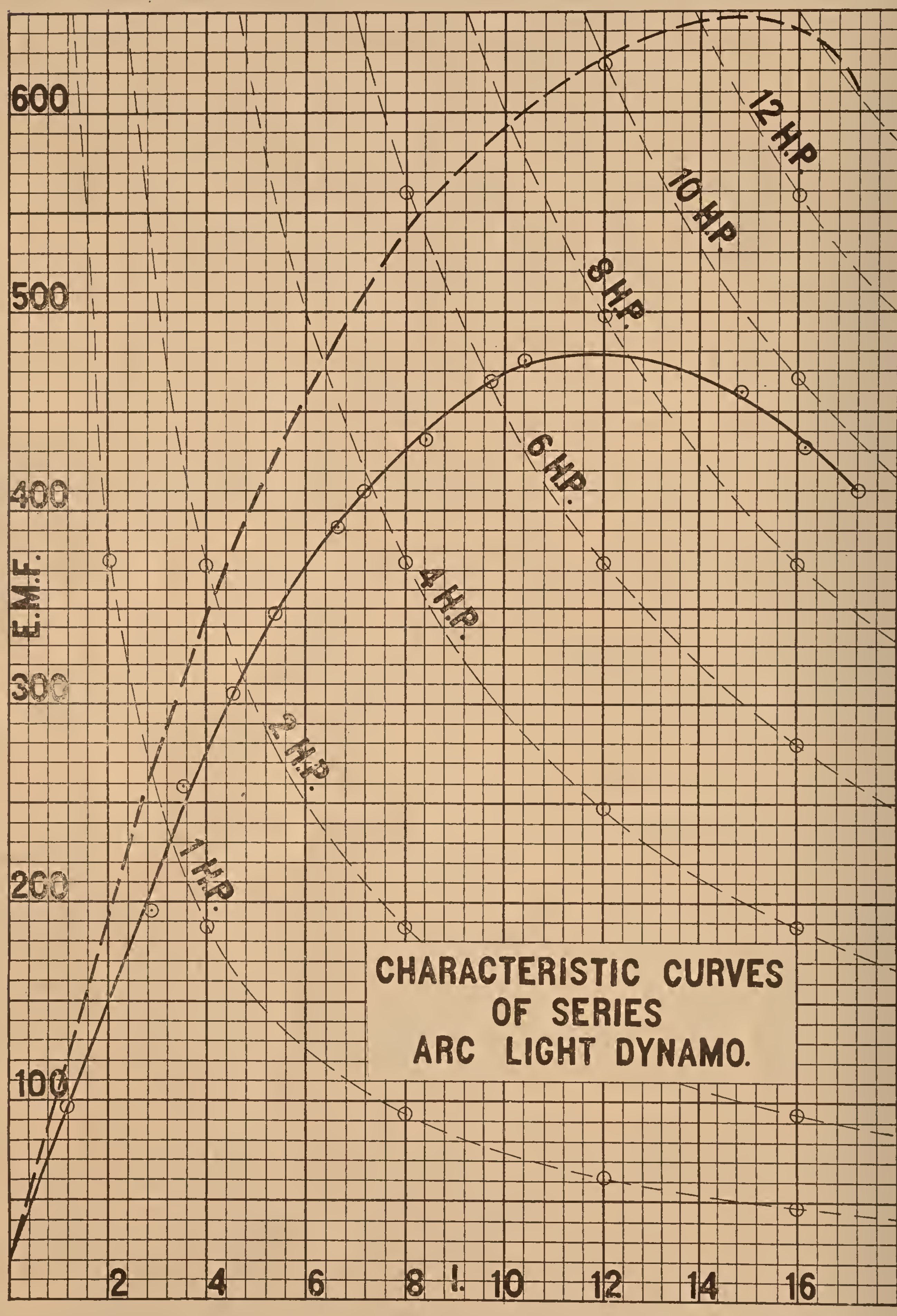
600
500
400
300
200
100
E.M.F.
2
4
6
8
10
12
14
16
12 H.P.
10 H.P.
8 H.P.
6 H.P.
4 H.P.
2 H.P.
1 H.P.
CHARACTERISTIC CURVES
OF SERIES
ARC LIGHT DYNAMO.

Fig. 8.

Internal and external characteristic curves of a small Wood arc light dynamo are shown in Fig. 8. The total voltage generated by the armature is equal to the voltage observed at the terminals plus the lost voltage of the armature and series coils.

This was calculated by the equation

$$E' = E + I\,(r_a + r_{se})$$

where r_a was 5.4 ohms and r_{se} was 6.83 ohms.

The observed voltages are corrected for a speed of 1150 revolutions.

The electrical efficiency for this machine was calculated and found as follows:

DATA FOR EFFICIENCY OF SMALL WOOD DYNAMO.

Speed	I	$E'\,I'$	$E\,I$	$\frac{E\,I}{E'\,I'}$
1150	1	288	88	31%
1150	4.4	1727	1408	81%
1150	4.6	1840	1509	82%
1150	6.0	2704	2280	84%
1150	7.0	3389	2884	85%

The usual use of the constant current dynamo is for arc lighting. Arc lamps are commonly run in series and require about 10 amperes, and a potential of about 50 volts across the terminals of each. To maintain a constant current in the circuit the E. M. F. at the brushes of the generator must then increase 50 volts as each lamp is thrown in.

Constant current dynamos are series wound. Of such machines, we know that with a variable resistance in the external circuit, the current, or E. M. F. or both will vary. In the case of a machine supplying a certain current, if the resistance is increased the current strength will fall, and the field coils being in series the magnetic field is weakened, thereby lowering the E. M. F. and still further lessening the current. On the other hand if the external resistance is reduced, a larger current flows and a correspondingly higher potential is generated. Obviously, if such a machine is required to give a constant current through a

variable resistance, there must be some means provided for raising and lowering the E. M. F.

For effecting such regulation there are these three methods: (1) Varying the speed. (2) Varying the field strength. (3) Changing the position of the brushes.

The first method is seldom made use of although in principle it is very simple. There must be an automatic regulation of speed and the E. M. F. of course rises and falls with it. Such regulation, on account of the inertia of the heavy moving parts of the engine and generator, is too slow for lighting service.

Regulation by the second method is obtained either by changing the number of active conductors in the field or by changing the connections of the coils from series to parallel and *vice versa*. Running on light load (few lamps in series) only enough turns in the field are left in circuit to maintain a current of 10 amperes, and as more lamps are added to the circuit more field turns are thrown in to strengthen the field and to raise the voltage. The disadvantage of this method is the small range of loads that can be economically carried. For as the field coils are thrown in the cores soon rapidly approach the point of saturation, beyond which a large increase of ampere-turns effects the E. M. F. very slightly. On the other hand the machine will not run well on very light loads, for the current being constant the reaction of the armature is constant and on the weakened field has a greatly increased effect of distortion upon the field and causes serious sparking at the brushes.

The third method that of shifting the brushes is the most common one. To understand the principle of this regulation it will be well to refer back to the figure showing the two paths of the current through a ring armature and out by the brushes, (see Fig. 25 in Instruction Paper on *Theory of Dynamo-Electric Machinery*). It will be seen readily that the maximum E. M. F. at the brushes is obtainable when they are at the neutral point, that is when all the amature coils on either side of the brushes generate an E. M. F. in the same direction. If the brushes are shifted from the neutral point then some of the coils on either side oppose the others on the same side and a reduced pressure at the brushes is the result. If the brushes were placed at points midway between the neutral

points, then on each side half the coils would oppose the other half and the pressure at the brushes would be nil, that is the algebraic sum of the E. M. F's of the coils in each half would be zero. Then by moving the brushes from this point toward the neutral point this sum, or the E. M. F. of the machine would increase gradually to the maximum. Such is the principle of this method of regulation.

A constant current machine running on light load will have its brushes in a position considerably off the neutral point, and as more lights are thrown into the circuit making the load heavier, they will be brought correspondingly nearer, maintaining sufficient E. M. F. at the brushes to force a current of constant value

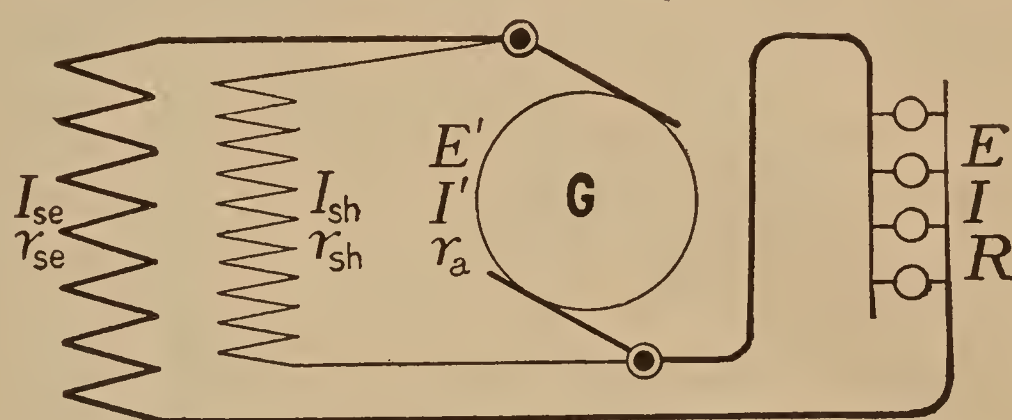

Fig. 9. Ordinary, or Short Shunt Compound Dynamo.

through the increasing external resistance. The shifting of the brushes is done automatically by electromagnets in circuit, which

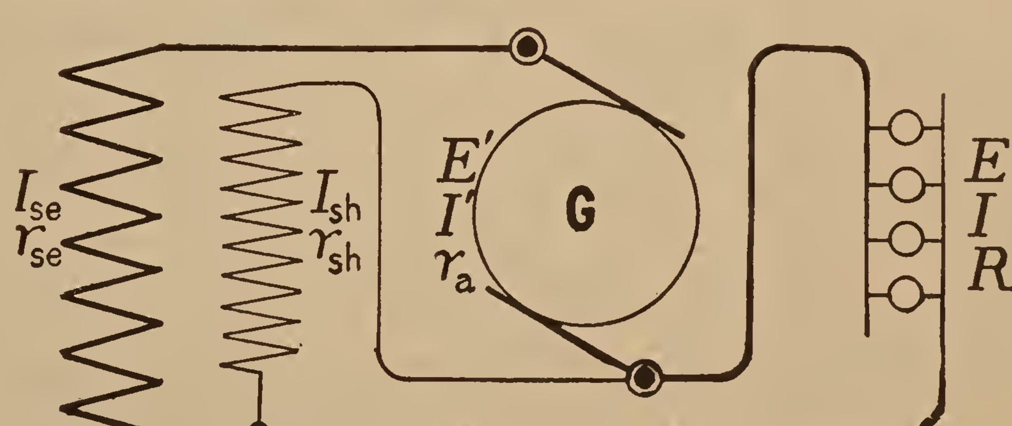

Fig. 10. Long Shunt Compound Dynamo.

act instantly to counteract any change of current strength flowing through them.

The **Compound-Wound Dynamo** (see diagrams Figs. 9 and 10), may be considered as a shunt dynamo to which some series windings have been added to compensate for the fall in voltage at

the brushes due to the demagnetizing effects of the armature, lost volts in armature, and to compensate for line losses as the load increases. The shunt circuit may either be connected to the brushes, in which case the machine is called the **Ordinary or Short Shunt Compound Dynamo** (see Fig. 9), or the shunt circuit may be connected to the terminals of the outside circuit in which case the machine is called a **Long Shunt Compound Dynamo** (see Fig. 10). Using the symbols as marked on these diagrams the equations for the ordinary or short shunt compound dynamo will be deduced. The total current is

$$I' = I + I_{sh} = I_{se} + I_{sh} = I + \frac{E + Ir_{se}}{r_{sh}}$$

It may also be written (see similar equation on page 11)

$$I' = \frac{E'}{r_a + \dfrac{(R + r_{se}) \times r_{sh}}{R + r_{se} + r_{sh}}}$$

or again it may be written

$$* \, I' = I \left\{ 1 + \frac{R + r_{se}}{r_{sh}} \right\} = I \times \frac{r_{sh} + r_{se} + R}{r_{sh}}$$

The value of the shunt current may be written

$$I_{sh} = \frac{E' - I'r_a}{r_{sh}} = \frac{E + Ir_{se}}{r_{sh}} = I \times \frac{r_{se} + R}{r_{sh}}$$

† The value of the total E. M. F. generated may be written

$$E' = E + I' r_a + I r_{se}$$

$$* \quad = E + \left\{ I + \frac{E + I r_{se}}{r_{sh}} \right\} r_a + I r_{se}$$

† The value of the total E. M. F. generated may also be expressed in terms of the useful voltage and the various resistances. It is equal to the sum of four lost voltages. The first of these voltages is E, the useful voltage. The next is the voltage lost in the series coil and is equal to $\frac{r_{se}}{R} \times E$.

Then the total voltage at the brushes is

$$E + \frac{r_{se}}{R} E \quad \text{or} \quad E \left\{ 1 + \frac{r_{se}}{R} \right\} \quad \text{or} \quad E \left\{ \frac{R + r_{se}}{R} \right\}$$

The lost voltage in the armature due to that part of the current that flows through the series and outside circuit is to the voltage of the series and outside circuit as the resistance of the armature is to the resistance of the series and outside circuit.

$$\begin{matrix}\text{Lost volts in armature} \\ \text{due to outside current}\end{matrix} : E \left\{ \frac{R + r_{se}}{R} \right\} :: r_a : r_{se} + R$$

$$\begin{matrix}\text{Lost volts in armature} \\ \text{due to outside current}\end{matrix} = E \left\{ \frac{r_a \,(R + r_{se})}{R \times (r_{se} + R)} \right\}$$

Similarly the lost voltage in the armature due to the current flowing in shunt field is to the voltage of the shunt field as the resistance of the armature is to the resistance of the shunt field.

$$\begin{matrix}\text{Lost volts in armature} \\ \text{due to shunt current}\end{matrix} : E \left\{ \frac{R + r_{se}}{R} \right\} :: r_a : r_{sh}$$

$$\begin{matrix}\text{Lost volts in armature} \\ \text{due to shunt current}\end{matrix} = \frac{E\,(R + r_{se})\, r_a}{R \times r_{sh}}$$

Therefore, the total voltage generated being equal to the sum of these four expressions it may be written

$$E' = E + \frac{E r_{se}}{R} + \frac{E\,(R + r_{se})\, r_a}{R\,(r_{se} + R)} + \frac{r_a\,(R + r_{se})\, E}{r_{sh} \times R}$$

As the third term when simplified has the same denominator as the second term the two may be combined, and as all four terms in the right hand side of the equation contain E it may be taken outside the parenthesis ; then,

$$E' = E \left\{ 1 + \frac{r_{se} + r_a}{R} + \frac{r_a\,(R + r_{se})}{R \times r_{sh}} \right\}$$

The electrical efficiency of the ordinary compound dynamo is equal to the useful energy divided by the sum of the useful energy in the outside circuit, plus energy lost in series coils, plus energy lost in shunt coils, plus energy lost in armature.

$$\eta_e = \frac{E\,I}{E'\,I'} = \frac{I^2\,R}{I^2\,R + I^2\,r_{se} + I_{sh}^{\,2}\,r_{sh} + I'^2\,r_a}$$

$$* = \frac{I^2\,R}{\dfrac{I^2\,(r_{se} + r_{sh} + R)^2 r_a}{r_{sh}^{\,2}} + \dfrac{I^2\,(r_{se} + R)^2}{r_{sh}} + I^2\,R + I^2 r_{se}}$$

$$\dagger = \frac{1}{\dfrac{(r_{se} + r_{sh} + R)^2 r_a}{r_{sh}^{\,2}\,R} + \dfrac{(r_{se} + R)^2}{r_{sh}\,R} + 1 + \dfrac{r_{se}}{R}}$$

For the **Long Shunt Compound-Wound Dynamo** (see Fig. 10) the equations may be written in a similar manner. The values of the total current generated will be

$$I' = I_{se} = I + I_{sh} = I + \frac{E}{r_{sh}} = I \frac{r_{sh} + R}{r_{sh}}$$

$$I_{sh} = \frac{E}{r_{sh}} = I \frac{R}{r_{sh}}$$

The total voltage generated in the armature is

$$E' = E + I' (r_a + r_{se}) = E + \left\{ I + \frac{E}{r_{sh}} \right\} (r_a + r_{se})$$

$$* = E \left\{ 1 + \frac{R + r_{sh}}{R\, r_{sh}} \right\} (r_a + r_{se})$$

† The electrical efficiency of the long shunt compound dynamo is

$$\eta_e = \frac{I^2 R}{I'^2 (r_a + r_{se}) + I_{sh}^{\ 2} r_{sh} + I^2 R}$$

$$* = \frac{I^2 R}{\left\{ I^2 + \frac{2 R I^2}{r_{sh}} + \frac{R^2 I^2}{r_{sh}^{\ 2}} \right\} (r_a + r_{se}) + \frac{I^2 R^2}{r_{sh}} + I^2 R}$$

$$\dagger = \frac{1}{\frac{r_a + r_{se}}{R} + 2 \left\{ \frac{r_a + r_{se}}{r_{sh}} \right\} + \frac{R (r_a + r_{se})}{r_{sh}^{\ 2}} + \frac{R}{r_{sh}} + 1}$$

The compound-wound dynamo by means of its shunt coils and its series coils is enabled to produce a practically constant voltage within the working limits of its capacity. This is not absolutely true for the voltage curve is a slightly curved line tending to rise slightly from no load to about half load and then falling again from about half load to full load.

As the load increases and the resistance of the outside circuit decreases the main current in the series field coils increases and the current in the shunt coils still remains constant as it is now fed with a constant voltage. Thus although there are more lost volts in the armature to cut down the voltage, and although there is a much greater demagnetizing effect produced by the armature yet the voltage supplied to the external circuit is still maintained at its constant value.

As the load decreases and the resistance of the outside circuit increases less current flows through the series coils and through the armature, and as there are less lost volts in the armature and a less demagnetizing effect it is readily seen that the magnetizing effect of the series coils is needed less now, and the shunt field coils which are still supplied at about the same constant voltage play relatively a much greater part in furnishing the magnetism of the dynamo. A compound dynamo therefore if properly proportioned, will supply a practically constant voltage at all loads. In the case of the ordinary or short shunt compound dynamo, the potential at the brushes is kept constant. In the case of the long shunt dynamo the potential at the terminal of the working circuit is constant. The latter arrangement therefore is somewhat preferable but either arrangement proves satisfactory in well designed dynamos as the actual value of the difference in the two cases is generally very slight.

In the case of the ordinary or short shunt compound dynamo the series coils furnish the excitation required to produce a potential such as will compensate for the lost voltage in the armature and the demagnetizing effects due to the armature. In the case of the long shunt dynamo the series coils compensate for these same losses as well as for the lost voltage of the series coils.

It is advisable and generally customary to put a somewhat greater number of series turns on the field coils than is necessary to overcome armature reactions and lost voltage in order to have the dynamo give a somewhat greater voltage at full load than at no load. This process which is called **overcompounding** is calculated for a rise of voltage of about four or five per cent. As the load increases an engine often runs a few revolutions slower, or there is a trifle more slipping of the belt which causes the speed of the armature to drop a little; the increasing load is also accompanied by a greater lost voltage in the line or feeders; hence the dynamo should be overcompounded to make up for these losses. If the load is at some distance from the generator there might be considerably more than 5 % drop of voltage at full load. This drop can be figured and a machine may be especially compounded for this loss at the time it is built. The object of course is to keep the voltage constant at the lamps, and if they are some distance

away and the load is constantly changing it is often necessary and advisable to run so-called *pressure wires* from the center of distribution back to a voltmeter in the dynamo room. Then if the dynamo is not overcompounded so as to give the proper pressure at all loads the pressure may be varied by adjusting the rheostat which is in series with the shunt coils of the dynamo. Even though the dynamo is properly compounded it is almost always necessary to regulate with the rheostat also in the case of incandescent lighting, especially where the lamps are distributed over a wide territory.

In designing a dynamo for any given output it is necessary to make due allowance for the total energy to be generated which is the total voltage E' multiplied by the total current I'. In order that the energy lost in the series field turns may not be too great, it is well to have them wound near the field cores so that each turn may be as short as possible and then the shunt coils may be wound outside of the series turns.

In Fig. 11 are shown some characteristic curves of a compound-wound Crocker-Wheeler dynamo running at 1500 revolutions per minute.

The upper curve is the external characteristic of the dynamo running with all the resistance cut out of the shunt field regulating rheostat. It is running, therefore with a maximum field excitation and giving its maximum voltage, about 127.8 volts at no load. It will be noted that as the load increases the voltage drops somewhat. It is evident that the magnetic flux due to the series ampere-turns on the field coil is not great enough to make up for the armature demagnetizing effects and the lost volts in the armature. Therefore there are not enough series turns, and the dynamo is undercompounded when running at 127.8 volts.

Next some of the resistance of the regulating rheostat is put in series with the shunt field until the voltage falls to 109.2 volts. By increasing the load the voltage increases, being from about 4 % to 7 % higher as the load increases than it was at no load. Now the rise in voltage, due to compounding, makes up for the loss in the line wires and is a little too great in the case of the 7 %, and in order to keep the lamps from burning too brightly the rheostat handle would have to be turned so as to cut the voltage down a little.

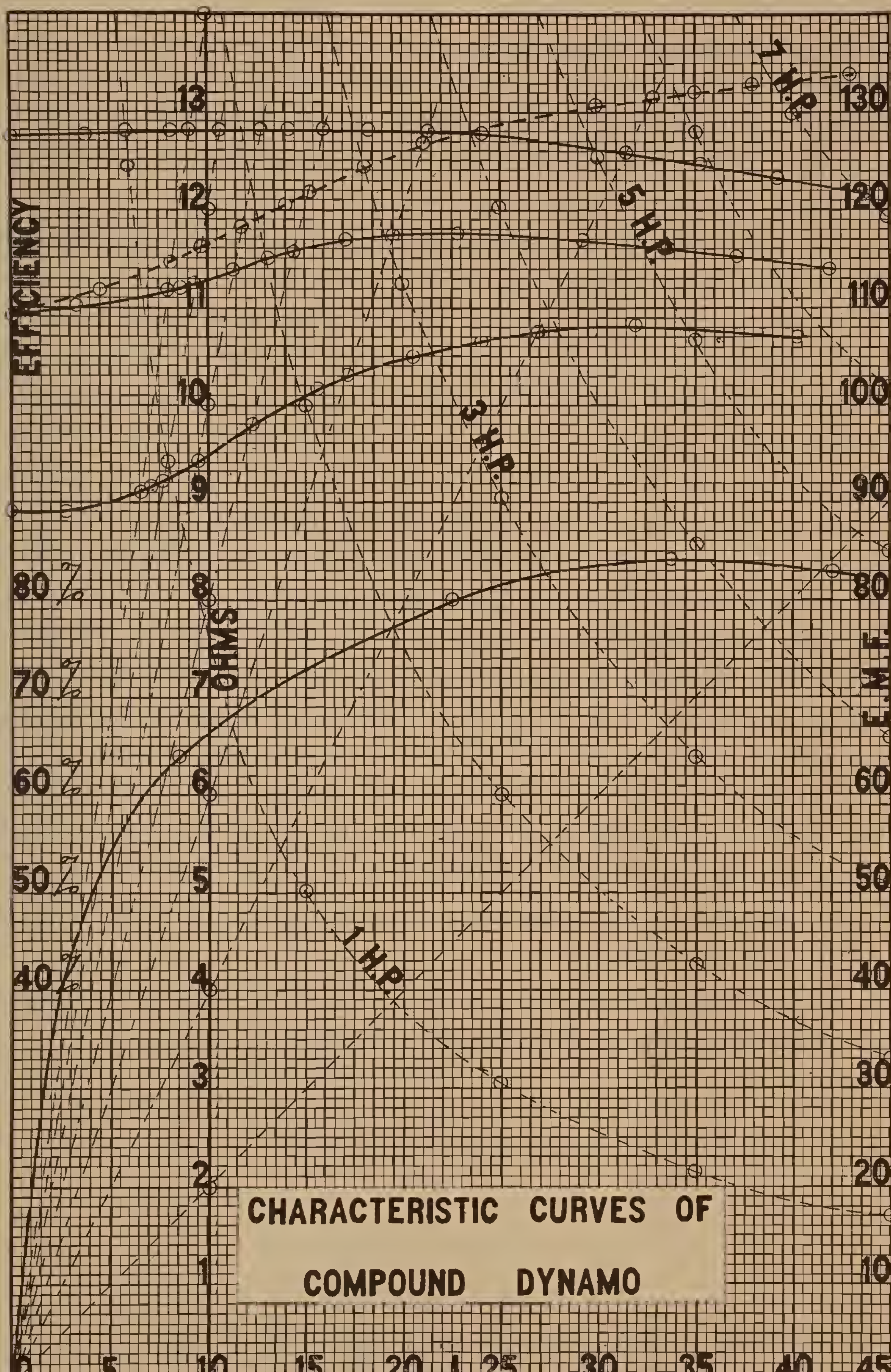

Fig. 11. Characteristic Curves and Efficiency Curve of a Crocker-Wheeler Compound Dynamo.

Judging from these two curves it appears that if the dynamo were run at a little higher initial voltage, say 112 or 115 it would be then running at just about the proper voltage for which it was compounded. The percentage of the overcompounding would then be about four or five per cent and the dynamo might run at varying loads with little or no need of adjusting the rheostat.

The curve shown by broken line (see Fig. 11) is the internal characteristic curve derived by adding the values of the lost volts in armature and in series field to the value of the external voltage.

The lower compound characteristic curve starting with an initial voltage of 89 shows that the dynamo is very much overcompounded when running at this voltage. The rheostat has been so adjusted that less current flows through the field coils, the shunt current is reduced and the value of the shunt ampere-turns is reduced. On the other hand the value of the series ampere-turns is as great as formerly as the load increases, and so the value of the series excitation is now large in comparison with that of the shunt. The voltage therefore increases greatly with the load, causing the dynamo to be greatly overcompounded when started at an initial voltage of 89.

In Fig. 11, is also given a curve of commercial efficiency for this 5 H. P. Crocker-Wheeler compound dynamo, the commercial efficiency being the useful electrical work, $E\,I$, derived from the dynamo, divided by the value of the mechanical work delivered to the pulley of the dynamo.

The following table contains the data from which the characteristic curves shown in Fig. 11 were drawn.

I	E	I	E	I	E
0	127.8	0	109.2	0	89.
3.6	128.0	3.4	110.0	2.7	89.7
8.4	128.0	8.7	112.0	7.2	91.3
14.2	127.7	13.2	115.0	11.3	96.4
18.4	127.7	17.1	117.0	15.6	101.8
23.8	127.6	22.6	117.0	20.6	105.0
27.2	127.2	25.6	116.8	24.6	105.4
30.9	126.0	29.3	116.0	27.9	107.5
35.2	124.0	33.7	116.0	32.0	108.2
39.3	122.9	37.1	115.9	36.1	108.0
43.8	121.9	42.8	114.0	40.3	107.0
				40.4	107.0

The characteristic curves of a 5 KW. Edison compound

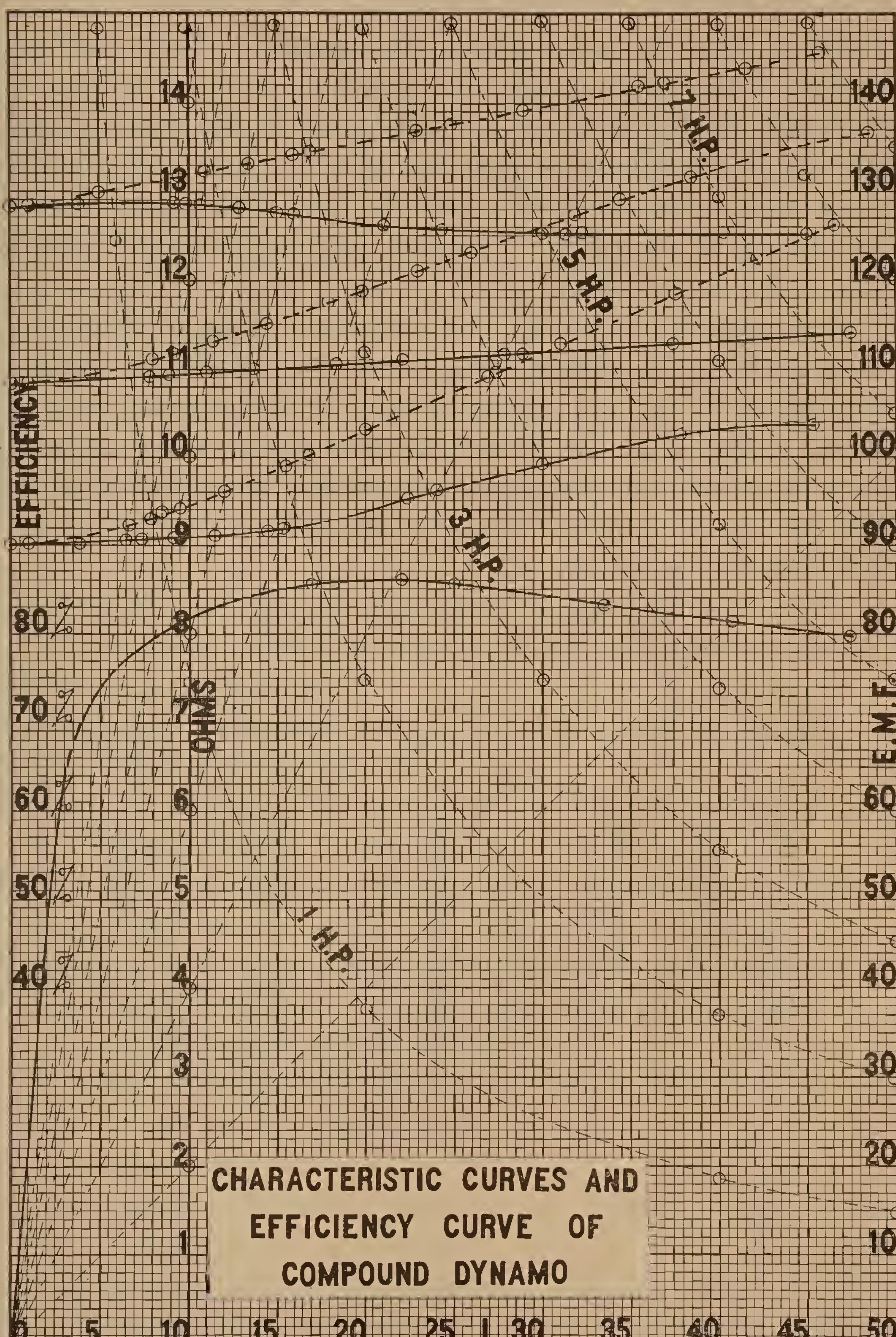

Fig. 12. Internal and External Characteristic Curves and Efficiency Curve of 5 KW. Compound Edison Dynamo.

dynamo are given in Fig. 12, for initial voltages of 131, 110, and 90, at a speed of 1,700 revolutions. In testing dynamos it is very difficult to keep the speed absolutely constant. There may be a variation in the speed of the main pulley from which the dynamo is run, and the belt may slip more and more as the load increases. However, as the voltage is proportional to the speed, the observed voltage may be corrected for the observed speed quite readily. The reading of the voltmeter and the tachometer should both be taken at the same instant.

The characteristics of the compound Edison dynamo as shown in Fig. 12, present very much the same phenomena as were exhibited by the characteristics of the Crocker-Wheeler dynamo in Fig. 11. The Edison dynamo, the curves of which are shown, is probably properly overcompounded for about 4% or 5% when running at an initial voltage of about 115. A curve of electrical efficiency is also shown.

The following table gives the data for the characteristic and efficiency curves of the 5 KW. compound Edison dynamo.

Speed.	E	E corrected to 1,700 rev.	I	Speed.	E	Corrected E	I	$\frac{E\,I}{E'I'}$
1740	131.5	128	0	1720	110	108.1	0	0
1725	130.0	128.1	3.8	1715	111	109.3	8.7	.82
1730	130.0	128.3	9.8	1690	111	111.0	22.0	.86
1725	128.5	126.7	14.7	1670	110	111.3	28.7	.87
1720	128.0	126.6	19.2	1665	112	113.1	37.3	.82
1715	126.5	125.4	24.3	1660	112	114.0	47.5	.80
1710	126.5	125.6	28.0	1730	91.5	90.0	.0	
1705	125.5	125.3	32.2	1730	91.5	90.0	7.4	
1685	124.0	125.2	36.0	1725	93.0	91.6	14.6	
1670	123.0	125.3	40.3	1715	96.5	95.7	22.4	
1665	123.0	125.6	45.0	1685	99.0	99.9	30.0	
1635	118.5	123.3	46.5	1660	99.5	101.9	38.0	
				1640	100.0	103.7	45.4	

CALCULATION OF DIRECT CURRENT DYNAMOS.

Note.—In the following pages will be found the electrical and magnetic details for the design of a 50 KW. shunt-wound dynamo. In designing each part, first the physical phenomena are discussed ; then the equation is given ; and then the calculation is made. These treatments of the physical phenomena should be carefully studied, especially those treating on the magnetic circuit appearing on pages 56 to 58. It is not so important to make the actual calculations as it is to understand quite thoroughly the phenomena underlying the working of the machine. However, it should be quite helpful to trace through the calculations if one is interested. The mechanical design of the dynamo will not be treated. The table of symbols is not to be studied but is simply arranged for easy reference. It is based on standards of notations, and is recommended for use by any who may become interested in dynamo design.

LIST OF SYMBOLS.

AT, at = ampere-turns.

AT = total number of ampere-turns on magnets, at normal load, or magnetizing force.

AT' = total magnetizing force required for maximum output of machine.

AT'' = total magnetizing force required for minimum output of machine.

at_a = magnetizing force required for armature core, normal load.

$at_{c.i.}$ = magnetizing force required for cast iron portion of magnetic circuit, normal load.

$at_{c.s.}$ = magnetizing force required for cast steel portion of magnetic circuit, normal load.

at_g = magnetizing force required for air gaps, normal load.

at_m = magnetizing force required for magnet frame, normal output.

at_p, at_{p_0} = magnetizing forces required for polepieces.

at_r = magnetizing force required for compensation of armature reactions.

$at_{w.i.}$ = magnetizing force required for wrought iron portion of magnetic circuit, normal load.

at_y, at_{y_0} = magnetizing forces required for yoke or yokes.
α = half pole-space angle (also angle of brush displacement).
$\mathfrak{B}$ = magnetic flux density in magnetic material, in lines per square centimetre.
$\mathfrak{B}''$ = magnetic flux density in magnetic material, in lines per square inch.
$\mathfrak{B}_a$, $\mathfrak{B}''_a$ = average density of magnetic lines in armature core.
$\mathfrak{B}_{a_1}$, $\mathfrak{B}''_{a_1}$ = maximum density of magnetic lines in armature core.
$\mathfrak{B}_{a_2}$, $\mathfrak{B}''_{a_2}$ = minimum density of magnetic lines in armature core.
$\mathfrak{B}_{c.i.}$, $\mathfrak{B}''_{c.i.}$ = mean density of magnetic lines in cast iron portion of frame.
$\mathfrak{B}_{c.s.}$, $\mathfrak{B}''_{c.s.}$ = mean density of magnetic lines in cast steel portion of frame.
$\mathfrak{B}_p$, $\mathfrak{B}''_p$ = mean density of magnetic lines in polepieces.
$\mathfrak{B}_{p_1}$, $\mathfrak{B}''_{p_1}$ = maximum density of magnetic lines in polepieces.
$\mathfrak{B}_{p_2}$, $\mathfrak{B}''_{p_2}$ = minimum magnetic density in polepieces.
$\mathfrak{B}_{w.i.}$, $\mathfrak{B}''_{w.i.}$ = magnetic density in wrought iron portion of magnetic circuit.
b = breadth, width.
b_a = breadth of armature cross-section, or radial depth of armature core.
b'_a = maximum depth of armature core.
b_y = breadth of yoke.
β = angle embraced by each pole.
β'_1 = percentage of effective arc, or effective field circumference.
γ = electrical conductivity, in mhos.
D, d, δ = diameter.
D_m = external diameter of magnet coil.
d_a = diameter of armature core.
d'_a = mean diameter of armature winding.
d''_a = external diameter of armature (over winding).
d'''_a = mean diameter of armature core.
d_c = diameter of core-portion of armature shaft.
d_f = mean diameter of magnetic field.
d_m = diameter of magnet core.
d_p = diameter of bore of polepieces.
δ_a = diameter of armature wire, in mils.
δ''_a = height of insulated armature conductor, in inches.

δ_i = thickness of iron laminæ in armature core, in inches.
δ_m diameter of magnet wire, bare, in mils.
δ'_m = diameter of magnet wire, insulated, in mils.
δ_{se} = diameter of series field wire.
δ_{sh} = diameter of shunt field wire.
$(\delta_a)^2$ = sectional area of armature conductor, in circular mils.
E, e = electromotive force, or pressure, in volts.
E = normal E. M. F. output, or voltage of generator; terminal E. M. F., or supply voltage of motor.
E' = total E. M. F. induced in armature of generator; counter E. M. F. of motor.
e = unit armature induction per pair of poles, volts per foot.
e' = specific induction of active armature conductor, volts per foot.
e_a drop of voltage due to armature resistance.
ϵ = factor of eddy current loss in armature, English measure (watts per cubic foot).
ϵ_1 = eddy current constant.
$\mathcal{F}$ = magneto-motive force, in gilberts.
F, f = force, or pull, in pounds.
$f(\mathcal{B})$ = function of $\mathcal{B}$; magnetizing force per centimetre length for density $\mathcal{B}$.
$f(\mathcal{B}'')$ = function of $\mathcal{B}''$; magnetizing force per inch length for density $\mathcal{B}''$.
$f(\mathcal{B}_a)$, $f(\mathcal{B}''_a)$ = specific magnetizing force of armature core.
$f(\mathcal{B}_{c.i.})$, $f(\mathcal{B}''_{c.i.})$ = specific magnetizing force of cast iron portion of magnetic circuit.
$f(\mathcal{B}_p)$, $f(\mathcal{B}''_p)$ = specific magnetizing force of polepieces.
$f(\mathcal{B}_{w.i.})$, $(f\,\mathcal{B}''_{w.i.})$ = specific magnetizing force of wrought iron portion of magnetizing circuit.
$f(\mathcal{B}_y)$, $f(\mathcal{B}''_y)$ = specific magnetizing force of yoke.
Φ = useful flux, *i. e.*, number of lines of force cutting armature conductors, at normal output.
Φ' = total flux, or total number of lines generated, at normal output (webers).
Φ'' = total flux per magnetic circuit.
$\mathcal{H}$ = magnetic flux density in air, or field density, in gausses (lines of force per square centimetre).

$\mathcal{H}''$ = field density, in lines of force per square inch.
h = height, thickness.
h_a = total height of winding space in armature (depth of slots).
h'_a = available height of armature winding space.
h_m = height of winding space on field magnets.
h'_m = net height of field winding.
h_p = height of polepieces.
h_y = height of yoke.
HP, hp = horse power.
η = factor of hysteresis loss in armature, English measure (watts per cubic foot).
η_1 = hysteretic resistance.
η_c = commercial efficiency.
η_e = electrical efficiency.
I, i = intensity of current, amperes.
I = current output, or amperage, of generator; current supplied to motor terminals.
I' = total current active in armature.
I_m = current in magnet winding.
I_{se} = total series current, in amperes.
I_{sh} = total shunt current, in amperes.
i_a = current density in armature conductor, circular mils per ampere.
i_m = current density in magnet wire, circular mils per ampere.
i_{se} = current density in series wire, circular mils per ampere.
i_{sh} = current density in shunt wire, circular mils per ampere.
K, k = constants.
k_1, k_2, k_3, . . . = various constants depending upon material, etc.
L, l = length, distance.
L_a = active length of armature conductor.
L_e = effective length of armature conductor.
L_m = total length of magnet wire, in feet.
L_{sh} = total length of shunt wire, in feet.
L_t = total length of armature conductor.
l_a = length of armature core.
l''_a = length of magnetic circuit in armature core.
$l''_{c.i.}$ = length of magnetic circuit in cast iron portion of field frame.

l''_g = length of magnetic circuit in air gaps.
l_p = length of polepieces, parallel to armature inductors.
l'_p = mean distance between pole-corners.
l''_p = length of magnetic circuit in polepieces.
l_t = mean length of turn of field magnet winding, in feet.
l''_r = length of mean shunt turn.
$l''_{w.i.}$ = length of magnetic circuit in wrought iron portion of field frame.
l'_y = length of yoke.
l''_y = length of magnetic circuit in yoke.
λ = factor of magnetic leakage.
$\lambda_m = \frac{1}{\rho_m}$ = specific length of magnet wire, in feet per ohm.
$M, M_1, \ldots$ = mass, volume.
M = mass of iron in armature core, in cubic feet.
μ = magnetic permeability
N, n = number.
N = number of revolutions of armature per minute.
N' = number of revolutions of armature per second.
N_1 = frequency of magnetic reversals, or number of cycles per second.
N_a = total number of turns on armature.
N_c = number of conductors around pole-facing circumference of armature.
N_m = number of turns on magnets.
N_{se} = number of series turns.
N_{sh} = number of shunt turns.
n_a = number of turns per armature coil.
n_c = number of armature coils, or number of commutator divisions.
n_1 = number of layers of wire on armature.
n_p = number of pairs of magnet poles.
n'_p = number of pairs of parallel branches in armature, or number of bifurcations of current in armature.
n_w = number of armature wires per layer.
n_z = number of magnetic circuits in dynamo.
$\mathfrak{P}, \mathfrak{P}_1, \mathfrak{P}_2, \ldots$ = permeances.
$\mathfrak{P}_1$ = relative permeance of gap-spaces.
$\mathfrak{P}_2$ = relative average permeance across magnet cores.

$\mathfrak{P}_3$ = relative permeance across polepieces.

$\mathfrak{P}_4$ = relative permeance between polepieces and yoke.

$\mathfrak{P}'$ = relative permeance of clearance space between poles and external surface of armature.

P' = total electrical energy, active in armature, or electrical activity of machine.

P'' = mechanical energy at dynamo shaft; *i. e.*, driving power of generator, output of motor.

P_A = total energy absorbed in armature.

P_M = total energy absorbed in field circuits.

P_a = energy absorbed in armature winding ($I^2 R$ loss).

P_e = energy absorbed by eddy currents, in watts.

P_h = energy absorbed by hysteresis, in entire armature core.

P_m = energy absorbed in magnet windings.

P_o = energy loss due to air-resistance, brush friction, journal friction, etc.

P'_o = energy required to run dynamo at normal speed on open circuit.

P_{se} = energy absorbed in series winding.

P_{sh} = energy absorbed in shunt winding.

π = ratio of circumference to diameter of circle, = 3.1416 or $\frac{22}{7}$ nearly.

$\mathcal{R}$ = reluctance of magnetic circuit, in oersteds.

R, r = electrical resistance, in ohms.

R = resistance of external circuit.

R_a = total resistance of armature wire, all in series.

r_a = armature resistance, cold, at 15.5° Centigrade.

r'_a = armature resistance, hot, at $(15.5 + \theta_a)$ degrees Centigrade.

r_m = magnet-resistance, cold, at 15.5° Centigrade.

r'_m = magnet-resistance, warm, at $(15.5 + \theta_m)$ degrees Cent.

r_{sh} = resistance of shunt winding, cold, at 15.5° Centigrade.

r'_{sh} = resistance of shunt winding, at $(15.5 + \theta_m)$ degrees C.

ρ_m = resistivity of magnet-wire, in ohms per foot.

S = surface, sectional area.

S_A = radiating surface of armature.

S_a = sectional area (corresponding to average specific magnetizing force) of magnetic circuit in armature core.

S_{a1} = minimum cross-section of armature core.

S_{a2} = maximum cross-section of armature core.

$S_{c.i.}$ = sectional area of magnetic circuit in cast iron portion of field frame.

$S_{c.s.}$ = sectional area of magnetic circuit in cast steel portion of field frame.

S_f = actual field area; *i. e.*, area occupied by effective inductors.

S_g = sectional area of magnetic circuit in air gaps.

S_M = radiating surface of magnets.

S_m = sectional area of magnet-frame, consisting of but one material.

S_p = area of magnet circuit in polepieces of uniform cross-section.

S_{p1} = minimum cross-section of polepieces.

S_{p2} = maximum area of magnetic circuit in polepieces.

$S_{w.i.}$ = sectional area of magnetic circuit in wrought iron portion of field frame.

S_y = area of magnetic circuit in yoke.

σ = factor of magnetic saturation.

T, t = time.

τ = torque, or torsional moment.

θ_a = rise of temperature in armature, in degrees Centigrade.

θ_m = rise of temperature in magnets, in degrees Centigrade.

v = velocity, linear speed.

v_c = conductor velocity, or cutting speed, in feet per second.

W_t, wt = weight.

wt'_a = weight of armature winding, covered wire.

wt'_m = weight of magnet winding, covered wire.

wt'_{se} = weight of series winding, covered wire.

wt'_{sh} = weight of shunt winding, covered wire.

WIRE TABLE. PROPERTIES OF COPPER WIRE.

		Area in		Weight per Unit of Length. Specific Gravity, 8.89.				Resistance in International Ohms at 68° F. According to Matthiessen's Standard of Resistivity.					Tensile Sgth. in Pounds.		Elong. % in 1 Foot.		Safe Cur. Amperes			Temperature Coefficients.	
Number B. & S. Gauge.	Diameter "d" in Mils. 1 Mil = .001 Inch.	Circular Mils d^2.	Thousandths of an Inch $d^2 \times .7854$.	Pounds per 1000 Feet.	Pounds per Mile.	Feet per Pound.	Ohms per Pound, Annealed.	Ohms per 1000 Ft. Annealed.	Ohms per 1000 Ft. Hard-Drawn.	Ohms per Mile. Annealed.	Ohms per Mile. Hard-Drawn.	Feet per Ohm Annealed.	Annealed.	Hard-Drawn.	Annealed.	Hard-Drawn.	Bright Wire Paneled.	Black Wire in Free Air.	Turns per Lin. In. Cotton Covered.	Temp. in Deg. C.	Resistance per Mil-Foot; Ohms.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
0000	460.000	211600.00	.166190	640.5	3381.4	1.561	.00007639	.04893	.050036	.25835	.26419	20440	5650	9975	45.0	5.00	146.0	346.0	1.6	0	1.00000
000	409.642	167806.43	.131794	508.0	2682.2	1.969	.0001215	.06170	.063094	.32577	.33314	16210	4475	7900	45.0	5.00	127.0	292.0	1.6	1	1.00387
00	364.796	133076.66	.104518	402.8	2126.8	2.482	.0001931	.07780	.079558	.41079	.42007	12850	3550	6250	45.0	4.00	110.0	247.0	1.8	2	1.00776
0	324.861	105534.50	.082887	319.5	1686.9	3.130	.0003071	.09811	.10033	.51802	.52973	10900	2800	4950	45.0	4.00	95.0	209.0	2.8	3	1.01166
1	289.296	83692.67	.065732	253.3	1337.2	3.947	.0004883	.1237	.12649	.65314	.66790	8083	2225	3925	42.0	4.00	83.0	177.0	3.2	4	1.01558
2	257.626	66371.31	.052128	200.9	1060.6	4.977	.0007765	.1560	.15953	.82368	.84239	6410	1750	3125	39.0	3.00	72.0	148.0	3.4	5	1.01950
3	229.422	52634.37	.041339	159.3	841.09	6.276	.001235	.1967	.20114	1.0386	1.0621	5084	1400	2450	36.0	3.00	63.0	127.0	3.9	6	1.02343
4	204.307	41741.32	.032784	126.4	667.39	7.914	.001936	.2480	.25361	1.3094	1.3392	4031	1100	1950	33.0	2.50	55.0	108.0	4.5	7	1.02738
5	181.941	33102.37	.025999	100.2	529.06	9.980	.003122	.3128	.31987	1.6516	1.6889	3197	875	1550	30.5	2.50	48.0	91.0	5.0	8	1.03134
6	162.022	26251.37	.020618	79.46	419.55	12.58	.004963	.3914	.40332	2.0825	2.1295	2535	700	1225	28.0	2.00	42.0	78.0	5.6	9	1.03531
7	144.285	20818.35	.016351	63.02	332.75	15.87	.007892	.4973	.50854	2.6258	2.6850	2011	550	975	26.0	2.00	37.0	66.0	6.2	10	1.03929
8	128.490	16509.64	.012967	49.98	263.89	20.01	.01255	.6271	.64127	3.3111	3.3859	1595	425	775	24.0	1.75	32.0	56.0	7.0	11	1.04328
9	114.434	13092.75	.010283	39.63	209.24	25.23	.01995	.7908	.80876	4.1753	4.2769	1265	325	600	21.5	1.75	28.2	48.0	7.5	12	1.04728
10	101.897	10383.02	.0081548	31.43	165.95	31.82	.03173	.9972	1.0199	5.2657	5.3848	1003	275	475	19.0	1.50	24.9	41.0	8.5	13	1.05129
11	90.743	8234.11	.0064656	24.93	131.63	40.12	.05045	1.257	1.2854	6.6369	6.7869	795.3	200	375	17.5	1.50	21.9	35.0	9.7	14	1.05532
12	80.808	6529.95	.0051287	19.77	104.39	50.59	.08022	1.586	1.6218	8.3741	8.5633	630.7	175	300	16.0	1.25	19.3	30.0	11.2	15	1.05935
13	71.962	5178.48	.0040672	15.68	82.791	63.79	.1276	1.999	2.0443	10.555	10.794	500.1	125	225	14.5	1.25	17.0	25.8	12.0	16	1.06339
14	64.084	4106.72	.0032254	14.43	76.191	80.44	.2028	2.521	2.5779	13.311	13.612	396.6	100	200	13.0	1.25	15.0	22.2	13.0	17	1.06745
15	57.069	3256.78	.0025579	9.858	52.050	101.4	.3225	3.179	3.2508	16.785	17.165	314.5	80	150	12.0	1.25	13.3	19.1	15.3	18	1.07152
16	50.821	2582.74	.0020285	7.818	41.277	127.9	.5128	4.009	4.0996	21.168	21.646	249.4	60	125	11.0	1.25	11.8	16.5	16.7	19	1.07559
17	45.257	2048.29	.0016087	6.200	32.736	161.3	.8153	5.055	5.1692	26.691	27.294	197.8	50	90	10.0	1.25	10.4	14.2	17.7	20	1.07968
18	40.303	1624.30	.0012757	4.917	25.960	203.4	1.296	6.374	6.5180	33.655	34.416	156.9	40	70	9.0	1.25	9.2	12.3	19.5	21	1.08378
19	35.890	1288.13	.0010117	3.899	20.595	256.5	2.061	8.038	8.2196	42.441	43.400	124.4	30	60	8.0	1.20	8.2	10.7	22.7	22	1.08788
20	31.961	1022.53	.00080231	3.092	16.324	323.4	3.278	10.14	10.372	53.539	54.749	98.66	25	45	7.0	1.20	7.2	9.2	27.0	23	1.09200
21	26.463	810.12	.00063626	2.452	12.946	407.8	5.212	12.78	. . .	67.479	. . .	78.24	23	39	6.0	1.00	. . .	. . .	31.0	24	1.09612
22	25.346	642.45	.00050457	1.945	10.268	514.2	8.287	16.32	. . .	85.114	. . .	62.05	21	32	5.0	1.00	. . .	. . .	34.4	25	1.10026
23	22.572	505.49	.00040015	1.542	8.142	648.4	13.18	20.32	. . .	107.29	. . .	49.21	18	26	5.0	1.00	. . .	. . .	38.2	26	1.10440
24	20.101	404.04	.00031733	1.223	6.457	817.6	20.95	25.63	. . .	135.33	. . .	39.02	16	20	5.0	1.00	. . .	. . .	42.3	27	1.10856
25	17.901	320.42	.00025166	.9699	5.121	1031	33.32	32.31	. . .	170.59	. . .	30.95	12	16	5.0	1.00	. . .	. . .	47.0	28	1.11272
26	15.940	254.10	.00019958	.7692	4.061	1300	52.97	40.75	. . .	215.16	. . .	24.54	. . .	. . .	. . .	. . .	. . .	. . .	52.0	29	1.11689
27	14.196	201.52	.00015827	.6100	3.221	1639	84.23	51.35	. . .	271.29	. . .	19.46	. . .	. . .	. . .	. . .	. . .	. . .	57.0	30	1.12107
28	12.642	159.81	.00012551	.4837	2.554	2067	133.9	64.70	. . .	242.09	. . .	15.43	. . .	. . .	. . .	. . .	. . .	. . .	63.4	40	1.16332
29	11.258	126.74	.000099536	.3836	2.025	2607	213.0	81.70	. . .	431.37	. . .	12.24	. . .	. . .	. . .	. . .	. . .	. . .	70.1	50	1.20625
30	10.025	100.51	.000078936	.3042	1.606	3287	338.6	103.0	. . .	543.84	. . .	9.707	. . .	. . .	. . .	. . .	. . .	. . .	77.1	60	1.24965
31	8.928	79.70	.000062599	.2413	1.274	4145	538.4	129.9	. . .	685.87	. . .	7.698	. . .	. . .	. . .	. . .	. . .	. . .	84.6	70	1.29327
32	7.950	63.20	.000049643	.1913	1.010	5227	856.2	163.8	. . .	864.87	. . .	6.105	. . .	. . .	. . .	. . .	. . .	. . .	92.7	80	1.33681
33	7.080	50.13	.000039368	.1517	.801	6591	1361	206.6	. . .	1090.8	. . .	4.841	. . .	. . .	. . .	. . .	. . .	. . .	101.6	90	1.37995
34	6.305	39.75	.000031221	.1203	.635	8311	2165	260.5	. . .	1375.5	. . .	3.839	. . .	. . .	. . .	. . .	. . .	. . .	112.1	100	1.42231
35	5.615	31.52	.000024759	.09543	.504	10482	3441	328.4	. . .	1734.0	. . .	3.045	. . .	. . .	. . .	. . .	. . .	. . .	119.7	. . .	. . .
36	5.000	25.00	.000019635	.07568	.400	13217	5473	414.2	. . .	2187.0	. . .	2.414	. . .	. . .	. . .	. . .	. . .	. . .	130.6	. . .	. . .
37	4.453	19.83	.000015574	.06001	.317	16666	8702	522.2	. . .	2757.3	. . .	1.915	. . .	. . .	. . .	. . .	. . .	. . .	140.6	. . .	. . .
38	3.965	15.72	.000012345	.04759	.251	21015	13870	658.5	. . .	3476.8	. . .	1.519	. . .	. . .	. . .	. . .	. . .	. . .	151.0	. . .	. . .
39	3.531	12.46	.0000097923	.03774	.199	26500	22000	830.4	. . .	4384.5	. . .	1.204	. . .	. . .	. . .	. . .	. . .	. . .	163.4	. . .	. . .
40	3.145	9.88	.0000077634	.02993	.158	33416	34980	1047.0	. . .	5528.2	. . .	.955	. . .	. . .	. . .	. . .	. . .	. . .	177.6	. . .	. . .

WIRE TABLE. INSULATED WIRE.

Gauge of Wire. B. W. G.	Gauge of Wire. B. & S.	Diameter of Wire (bare). inch	Diameter of Wire (bare). mm	Single Cotton Insulation. Thickness of insulation. Inch.	Single Cotton Insulation. Ratio of bare diameter to thickness of insulation.	Single Cotton Insulation. Weight of insulation per 100 lbs. of covered wire.	Single Cotton Insulation. Weight of covered wire per lb. of bare wire, k_5.	Double Cotton Insulation. Thickness of insulation. Inch.	Double Cotton Insulation. Ratio of bare diameter to thickness of insulation.	Double Cotton Insulation. Weight of insulation per 100 lbs. of covered wire.	Double Cotton Insulation. Weight of covered wire per lb. of bare wire, k_5.
1	..	.300	7.62	..	..	..	..	.020	15	2.28	1.022
..	1	.289	7.34	..	..	..	..	.020	14.45	2.32	1.023
2	..	.284	7.21	..	..	..	..	.020	14.2	2.33	1.023
3	..	.259	6.58	..	..	..	..	.020	12.95	2.40	1.024
..	2	.258	6.55	..	..	..	..	.020	12.9	2.40	1.024
4	..	.238	6.04	..	..	..	..	.020	11.9	2.50	1.025
..	3	.229	5.82	..	..	..	..	.020	11.45	2.55	1.025
5	..	.220	5.59	..	..	..	..	.020	11	2.65	1.026
..	4	.204	5.18	.012	17	2.20	1.022	020	10.2	2.85	1.028
6	..	.203	5.16	012	16.9	2.20	1.022	.020	10.15	2.86	1.028
..	5	.182	4.62	.012	15.15	2.27	1 0227	.018	10.1	2.87	1.028
7	..	.180	4.57	.012	15	2.28	1.0228	.018	10	2.90	1.029
8	..	.165	4.19	.012	13.75	2.33	1 0233	.018	9 17	3.20	1.032
..	6	.162	4.12	.010	16.2	2.24	1.0224	.018	9	3.25	1.032
9	..	.148	3.76	.010	14.8	2.30	1.023	.016	9.25	3.15	1.031
..	7	.144	3.66	.010	14.4	2 32	1.0232	.016	9	3.25	1.032
10	..	.134	3.40	.010	13.4	2.36	1.0236	.016	8.4	3.55	1.035
..	8	.1285	3.27	.010	12.85	2.40	1.024	.016	8	3.75	1.037
11	..	.120	3.05	.010	12	2.50	1.025	.016	7.5	4.10	1.041
..	9	.1144	2.91	.010	11.4	2.55	1.0255	.016	7.1	4.35	1 043
12	..	.109	2.77	.010	10.9	2.66	1.0266	.016	6.8	4.60	1.046
..	10	.102	2.59	.010	10.2	2.85	1.0285	.016	6.4	5.00	1.05
13	..	.095	2.41	.010	9.5	3.10	1.031	.016	5.9	5.55	1.055
..	11	.091	2.31	.010	9.1	3.25	1.0325	.016	5.7	5.85	1.058
14	..	.083	2.11	.007	12	2.50	1.025	.016	5.2	6.60	1.066
..	12	.081	2.06	.007	11.6	2.54	1.0254	.016	5.1	6.80	1.068
15	13	.072	1.83	.007	10.3	2.80	1.028	.016	4.5	7.80	1.078
16	..	.065	1.65	.007	9.3	3.15	1.0315	.016	4.1	8.60	1.086
..	14	064	1.63	.007	9.1	3.25	1.0325	.016	4	8.80	1.088
17	..	.058	1.47	.007	8.3	3.60	1.036	.014	4 1	8.60	1.086
..	15	.057	1.45	.007	8.1	3.70	1.037	.014	4.1	8.60	1.086
..	16	.051	1.30	.007	7.3	4.20	1.042	.014	3.6	9.60	1.096
18	..	.049	1.25	.007	7	4.40	1.044	.014	3.5	9.80	1.098
..	17	.045	1.15	.005	9	3.25	1.0325	.012	3.75	9.30	1.093
19	..	.042	1.07	.005	8.4	3.55	1.0355	.012	3.5	9.80	1.098
..	18	.040	1.02	.005	8	3.75	1.0375	.012	3 33	10.10	1 101
..	19	.036	0.91	.005	7.2	4.30	1.043	.005*	7.2	5.60	1.056
20	..	035	0 89	.005	7	4.40	1.044	.005*	7	6.00	1.06
21	20	032	0.81	.005	6.4	5.00	1.05	.005*	6.4	6.60	1.066
22	21	028	0 71	.005	5.6	6.00	1 06	.004*	7	6.00	1.06
23	22	.025	0.64	.005	5	7.00	1.07	.004*	6.25	7.00	1 07
24	23	.022	0.56	.005	4.4	8.00	1.08	.004*	5.5	8.00	1.08
25	24	.020	0.51	.005	4	8.80	1.088	.004*	5	8.80	1.088
26	25	.018	0.46	.005	3.6	9.60	1.096	.004*	4.5	9.60	1.096
27	26	.016	0.41	.005	3.2	10.40	1.104	.004*	4	10.40	1.104
28	27	.014	0.36	.005	2.8	11.25	1.1125	.004*	3.5	11.25	1.112
29	28	.013	0.33	.005	2 6	11.65	1.1165	.004*	3.25	11.65	1.116
30	..	.012	0.31	.005	2.4	12.05	1.1205	.004*	3	12.05	1.120
..	29	.011	0.28	.005	2.2	12.45	1.1245	.004*	2.75	12.45	1.124

* Double silk: 1 mil of silk insulation taken equal in weight to 1.25 mil of cotton covering.

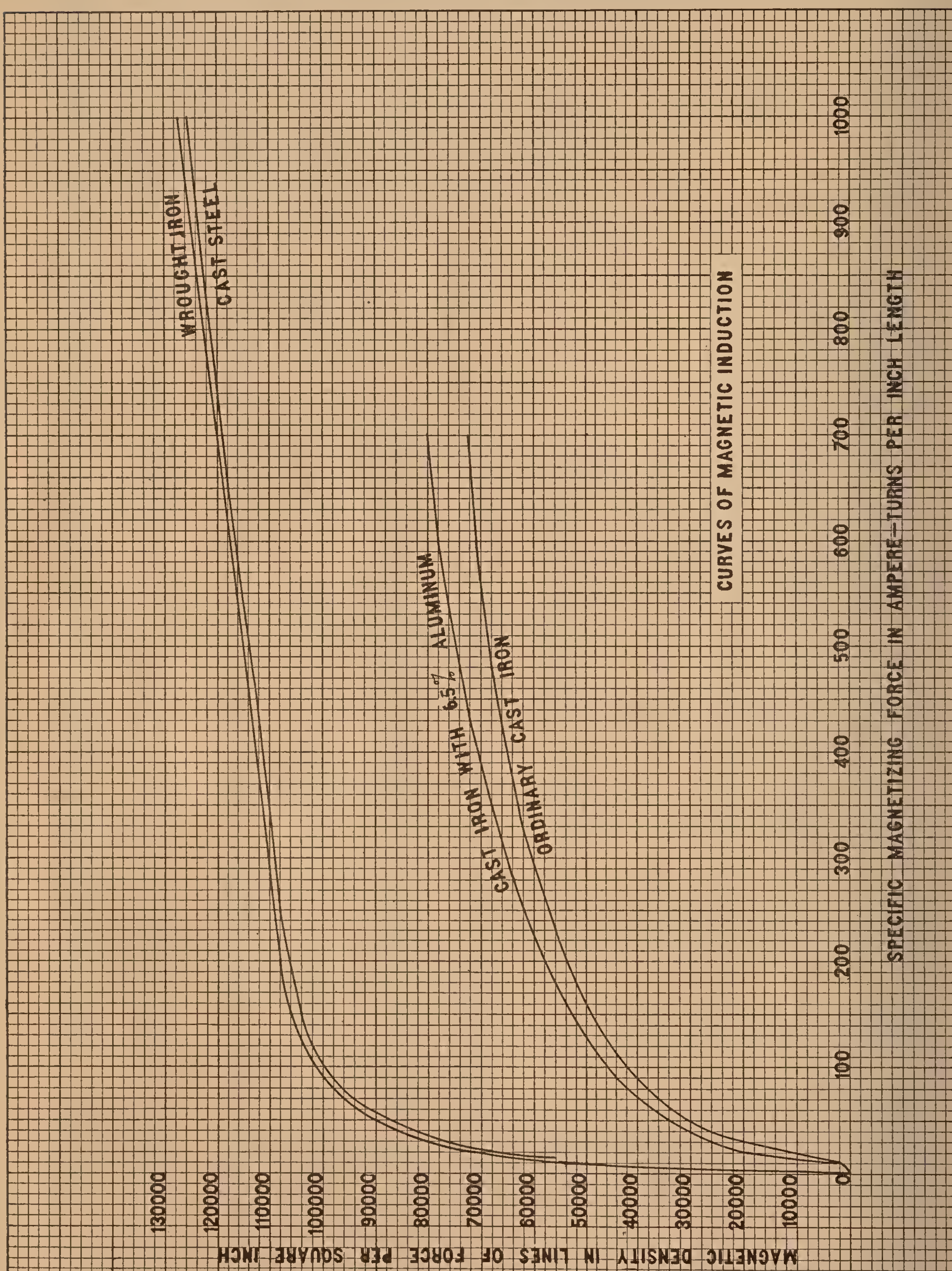
CURVES OF MAGNETIC INDUCTION
WROUGHT IRON
CAST STEEL
CAST IRON WITH 6.5% ALUMINUM
ORDINARY CAST IRON
MAGNETIC DENSITY IN LINES OF FORCE PER SQUARE INCH
SPECIFIC MAGNETIZING FORCE IN AMPERE-TURNS PER INCH LENGTH
130000
120000
110000
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
100
200
300
400
500
600
700
800
900
1000

Fig. 13.

Calculation of a Bipolar, Single Magnetic Circuit, Smooth-Drum, High-Speed Shunt Dynamo.

50 KW. Upright Horseshoe Type. Wrought-Iron Cores and Yoke, Cast-Iron Polepieces.

250 Volts. 200 Amperes. 1050 Revs. per Min.

(*a*) Calculation of Armature.

1. Length of Armature Conductor.

An electromotive force of one volt is generated by a conductor that cuts 100,000,000 C. G. S. lines of force per second. As the English system of units is still the standard in this country, one foot will be taken as the unit length of conductor, one foot per second the unit linear velocity, and one magnetic line of force per square inch as the unit field strength. Then every foot (12 in.) of inductor, moving at the rate of one foot (12 in.) per second in a field having one magnetic line of force per square inch will generate an E. M. F. of

$$\frac{12 \times 12 \times 1}{100{,}000{,}000} = \frac{144}{10^8} \text{ volt.}$$

As the armature of an ordinary bipolar dynamo has two parallel conductors each generating the same E. M. F.; and as these conductors are in parallel, two feet of conductor will be used in generating 144×10^{-8} volt or in other words each foot of the total length of conductors will generate only 72×10^{-8} volt if moving at unit velocity in unit field.

As this theoretical value of "unit armature induction" assumes that there is a magnetic field entirely surrounding the armature, it will have to be modified so as to take into account the fact that the fringe of magnetic lines from the pole pieces only partially surround the armature. For a 50 KW. bipolar dynamo with smooth-drum armature the polar arc (see figure 14) may be taken for the present as about 124°. It is found from actual practice that for a machine having a polar arc of about 124°, the

unit armature induction will not be the theoretical value of 72×10^{-8} but will be about

$$e = 61 \times 10^{-8} \text{ volts.}$$

* The "specific armature induction," *i. e.*, the induction per unit length of conductor moving at velocity v_c, in a magnetic field of strength, $\mathcal{H}''$, will be

$$e' = e \times v_c \times \mathcal{H}'' \text{ volts.}$$

where e' = specific induction of active armature conductor, in volts per foot of conductor;

e = unit armature induction per pair of armature circuits in volts per foot of conductor;

v_c = conductor-velocity, or cutting speed, in feet per second;

$\mathcal{H}''$ = field density, in magnetic lines of force per square inch.

It is customary to take the conductor velocity v_c, as about 50 feet per second for a 50 KW bipolar dynamo having a drum armature; also to take the field density $\mathcal{H}''$ as about 22,000 if the machine has cast iron polepieces. Therefore the value of e' may be written,

$$e' = \frac{61 \times 50 \times 22{,}000}{100{,}000{,}000} = \frac{671}{1{,}000}$$

Knowing the specific armature induction, e', the voltage induced by one foot of conductor, and knowing the voltage, E', that the armature is required to induce, one may easily find the total length of *active* wire, L_a, of the armature.

$$L_a = \frac{E'}{e'} = \frac{E' \times 10^3}{671}$$

where L_a = total length of active conductor (on whole circumference opposite polepieces);

E' = total E. M. F. to be generated in armature; *i. e.*, volt output plus additional volts to be allowed for drop due to internal resistance.

For a dynamo of 50 KW. capacity it is necessary to add about 6% to the value of E, the voltage wanted by the external circuit, in order to get E', the total E. M. F. to be generated in the armature. If E is 250, E' is 106% of 250 or 265, and

$$L_a = \frac{265 \times 10^3}{671} = \textbf{395 feet} \text{ of } \textit{active} \text{ conductor.}$$

The part of the conductor passing over the ends of the armature core is not active in cutting lines of magnetic force and so this

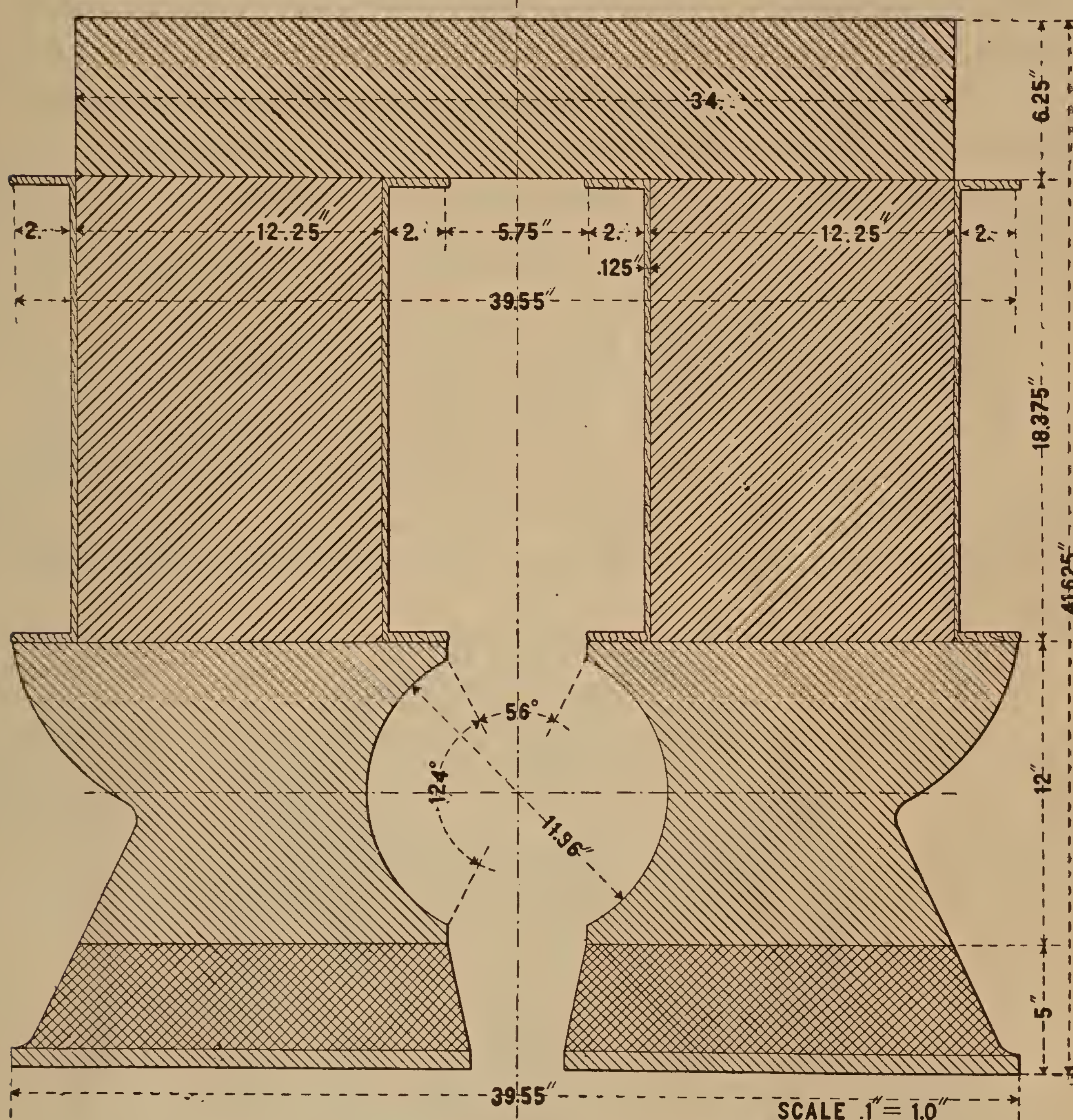

Fig. 14. Magnetic Circuit of 50 KW. Dynamo.

length of conductor will have to be increased when the dimensions of the iron core of the armature are known.

2. Sectional Area of Armature Conductor, and Selection of Wire.

† The cross section of wire to be chosen should be large enough so as not to be unduly heated by the current it has to carry. It is well to allow about 600 circular mils of copper conductor to 1

ampere of current, which is a current density of about 2,100 amperes per square inch of copper. Therefore to get the number of circular mils of copper to be provided multiply 600 by the current to be generated. There is to be furnished to the outside circuit 200 amperes. The armature will have to furnish this plus the current that goes through the shunt field. This latter value is so small however that it may be omitted with only trifling error or one may choose slightly larger wire for the armature than is needed for the 200 amperes. The cross section of conductor required therefore will be

$$200 \times 600 \text{ circular mils or } 120{,}000 \text{ circular mils.}$$

As there are two conductors to carry this current each conductor should have 60,000 circular mils. By reference to the B. & S. wire table on page 44 it will be seen that No. 2 wire has a cross section of 66,371 circular mils.

As No. 2 wire is too stiff to wind on the armature, however,

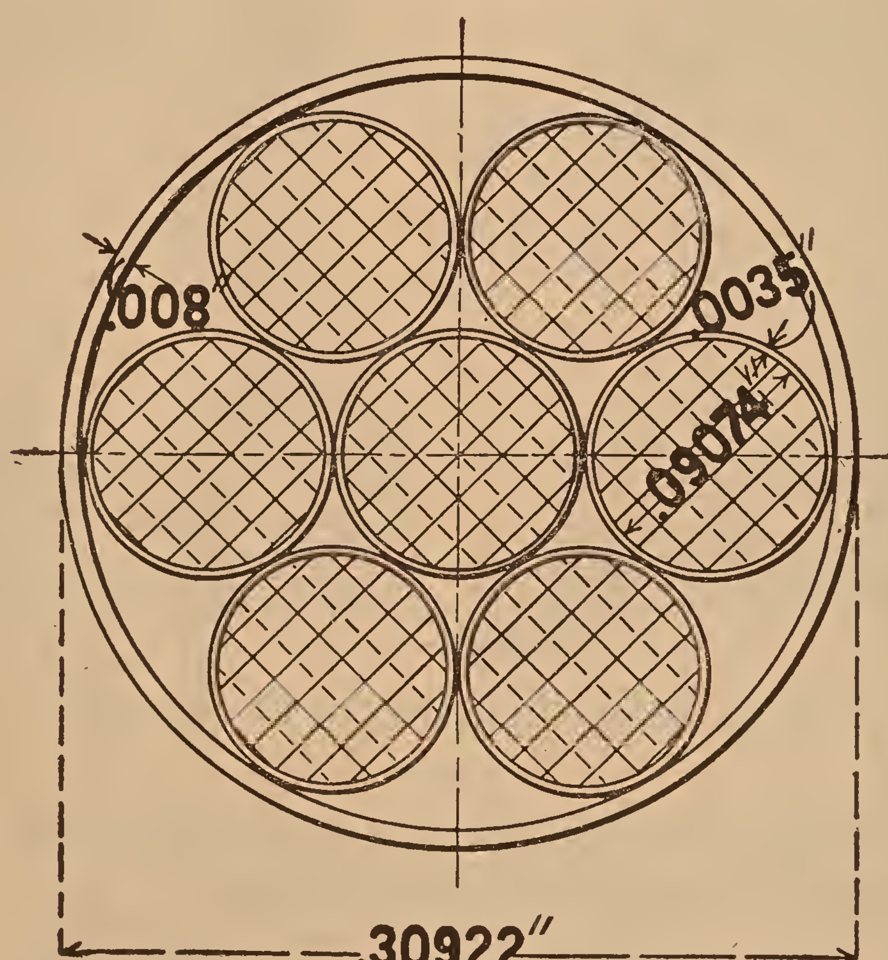

Fig. 15. Armature Conductor.

a cable made up of seven strands of No. 11 wire, having a copper cross section of $7 \times 8{,}234$ circular mils or a total of 57,638 circular mils is used. This will be a little higher current density than

was calculated upon at first but is not at all excessive. The diameter of No. 11 B. & S. wire is .09074 inch and a single cotton insulation of .007 inch is put on each strand and the seven strands are covered with a double cotton insulation of .016 inch. This will give the cable composed of seven strands of No. 11 B. & S. insulated wire a diameter (see Fig. 15) of

$$\delta'_a = 3 \times (.09074 \text{ inch} + .007 \text{ inch}) + .016 \text{ inch}$$
$$= \mathbf{.30922 \text{ inch.}}$$

3. Diameter of Armature Core.

* If the speed N is 1,050 revolutions per minute or $\frac{1050}{60}$ per second, and d'_a is the mean diameter of the armature winding in inches, or $\frac{d'_a}{12}$ in feet, then the cutting speed of the conductor in feet per second will be represented by,

$$v_c = \frac{d'_a \times \pi}{12} \times \frac{N}{60}$$

or

$$d'_a = \frac{12 \times 60}{\pi} \times \frac{v_c}{N} = \frac{12 \times 60 \times 50}{\pi \times 1050} = 10.91''.$$

It is found from actual practice that the ratio of the diameter of the armature, d_a, to the mean diameter of the armature

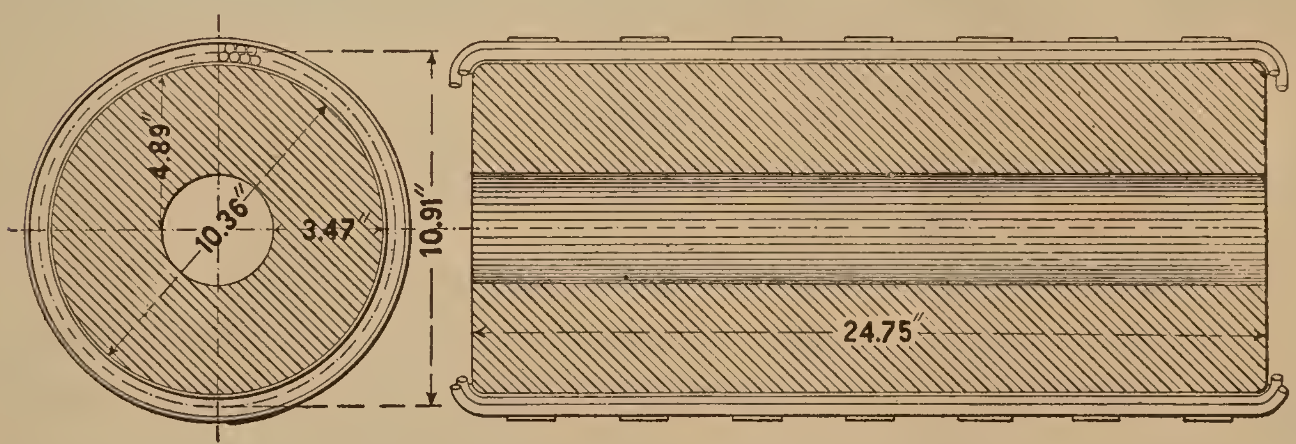

Fig. 16. Details of Armature.

winding, d'_a, is about .95 for drum armatures between eight and ten inches in diameter. Therefore (see Fig. 16)

$$d_a = .95 \text{ of } 10.91 \text{ inches, or } \mathbf{10.36 \text{ inches.}}$$

4. Length of Armature Core.

† Knowing the number of conductors that can be laid on the surface of the armature core, and the available depth for the windings, one may easily determine the number of conductors that can be wound on the armature; and knowing this and the length of active armature conductor, the length of the armature core may be determined. For a machine generating less than 300 volts and having a drum armature of the size of the one under consideration about 8% of the surface of the armature core is given up to division strips or driving horns.

$$* \text{ Then } n_w = \frac{.92 \times d_a \times \pi}{\delta_a'}$$

$$= \frac{.92 \times 10.36 \times \pi}{.30922} = 97 \text{ or } 96.$$

where n_w = the number of armature wires per layer;
d_a = the diameter of the armature core, in inches;
δ'_a = the width of insulated armature conductor, in inches;
.92 = the portion of the surface to be occupied by the conductors.

For a drum armature of the size of the one under consideration the height of the windings should be about .55 of an inch and of this space about .06 inch will be taken up by the insulation between windings and the armature, and .05 inch by binding wires. This leaves a net height of about .44 of an inch for the conductor. Then the number of layers of conductors will be

$$n_1 = \frac{h'_a}{\delta''_a} = \frac{.44}{.30922} = 1\tfrac{1}{2} \text{ or } 2$$

where n_1 = number layers of armature wire;
h'_a = net height of winding space, in inches;
δ''_a = height of insulated conductor, in inches.

By dividing the length of active armature conductor by the number of conductors we obtain the length of one active conductor which is the length of the armature core (see Fig. 16).

$$l_a = \frac{12 \times L_a}{n_w \times n_1} = \frac{12 \times 395}{96 \times 2} = 24\tfrac{3}{4} \textbf{ inches approx.}$$

where l_a = length of armature core parallel to pole faces, in inches;
L_a = length of active armature conductor in feet;
n_w = number of wires per layer;
n_1 = number of layers of wire on armature.

5. Arrangement of Armature Windings.

† For machines under 300 volts it is customary to have from 40 to 60 commutator segments. With this number of segments the voltage between two consecutive ones is low, and the pulsating current is within a fraction of one per cent of being a steady current. The number of commutator divisions, n_c, will be found by multiplying the number of wires per layer, n_w, by the number of layers, n_l, and dividing the product by some even number that gives a quotient which is between 40 and 60.

$$n_c = n_w \times n_l \div 4 = 48.$$

The number of convolutions per commutator segment, n_a will be

$$n_a = \frac{n_w \times n_l}{2 \times n_c} = \frac{96 \times 2}{2 \times 48} = \mathbf{2}$$

since it takes two conductors to make one turn. Therefore to sum up we have **48 coils,** each consisting of **2 turns** of a cable having **7 No. 11 B. & S. wires.**

6. Total Length of Armature Conductor, Weight and Resistance.

In order to connect the ends of the active conductors, turn the corners, etc., for this drum armature the total length of armature conductor will need to be about $1\frac{3}{4}$ times the active conductor.

$$L_t = 1.75 \times L_a = 1.75 \times 395 \text{ feet} = \mathbf{691\ feet.}$$

The weight of the conductor will be as follows: — A copper wire .001 in diameter weighs .00000303 pounds per foot of length. Therefore the weight of the total length of the copper in the armature conductor would be

$$\begin{aligned} wt_a &= k_5 \times L_t \times \delta_a^2 \times .00000303 \\ &= 1.03 \times 691 \times 57638 \times .00000303 = \mathbf{124\ pounds.} \end{aligned}$$

where wt_a = weight of bare armature winding in pounds;

k_5 = ratio between weights of the insulated wire and bare wire;

L_t = total length of armature conductor in feet;

δ_a^2 = area of conductor in circular mils.

The **resistance** of the armature will be as follows: — The total length of armature wire 691 feet is arranged in two parallel

circuits $345\frac{1}{2}$ feet long. These two paths are each composed of seven No. 11 B. & S. wires.

The resistance of 1,000 feet of No. 11 B. & S. wire is 1.311 ohms.

Therefore the resistance of the armature is,

$$R_a = \frac{1}{2 \times 7} \times \frac{345.5}{1{,}000} \times 1.311 \text{ ohms} = \mathbf{.0324\ ohm.}$$

7. Radial Depth of Armature Core, Minimum and Maximum Cross Section, and Average Magnetic Density of Armature Core.

*The following formula determines the proper size for the necessary strength of the armature shaft where it passes through the iron core of the armature.

$$d_c = k_9 \times \sqrt[4]{\frac{P'}{N}} = 1.3 \times \sqrt[4]{\frac{50{,}000}{1{,}050}} = \mathbf{3.42\ inches.}$$

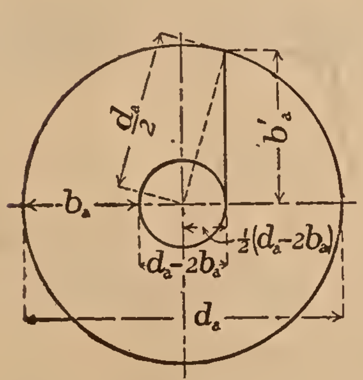

Fig. 17.

where d_c = diameter of armature shaft at core in inches;

P' = capacity of machine in watts;

N = speed, in revolutions per minute;

k_9 = constant depending upon capacity of machine.

Therefore the breadth of armature cross section, or radial depth of armature core is

$$b_a = \frac{1}{2}(d_a - d_c) = \frac{10.36 - 3.42}{2} = \mathbf{3.47\ inches.}$$

where b_a = radial depth of armature core, in inches;

d_a = diameter of armature core, in inches.

d_c = diameter of core section of armature shaft.

The maximum depth of armature core (see Fig. 17) is,

$$b'_a = \sqrt{\frac{d_a^2}{4} - \frac{(d_a - 2\,b_a)^2}{4}}$$

$$= \sqrt{\frac{(10.36)^2}{4} - \frac{(3.42)^2}{4}} = \mathbf{4.89\ inches.}$$

† The cross section of the magnetic field in the armature is equal to

$$S''_{a1} = 2 \times l_a \times b_a \times k_2$$
$$= 2 \times 24.75 \times 3.47 \times .95 = \textbf{163 square inches.}$$
$$S''_{a2} = 2 \times l_a \times b'_a \times k_2$$
$$= 2 \times 24.75 \times 4.89 \times .95 = \textbf{230 square inches.}$$

where S''_{a1} = minimum cross section of armature core, in square inches;

S''_{a2} = maximum cross section of armature core, in square inches;

l_a = length of armature core, in inches;

b'_a = radial depth of armature core, in inches;

k_2 = ratio of net iron section to total cross section of armature core.

The useful magnetic flux in the armature may be obtained as follows: The

$$\text{E. M. F.} = \frac{\text{Number of C. G. S. lines cut per second}}{10^8}$$

$$E' = \frac{N \times N_c \times \Phi}{60 \times 10^8} \text{ volts.}$$

where E' = total E. M. F. induced in armature;

N = number of armature revolutions per minute;

N_c = total number of conductors all around pole facing surface of armature;

Φ = total number of useful magnetic lines, in webers.

$$\text{or} \quad \Phi = \frac{60 \times 10^8 \times E'}{N \times N_c}$$

$$= \frac{60 \times 10^8 \times 265}{1050 \times 192} = \textbf{7,886,905 webers.}$$

Therefore the density of magnetic lines per square inch at the minimum cross section of the armature core is

$$\mathcal{B}''_{a1} = \frac{7,886,905}{163} = \textbf{48,386 lines} \text{ per square inch.}$$

and the density at the maximum cross section is

$$\mathcal{B}''_{a2} = \frac{7,886,905}{230} = \textbf{34,291 lines} \text{ per square inch.}$$

Next we wish to find the number of ampere-turns required to furnish this induction. The law for the magnetism in a magnetic circuit is exactly similar to the law for current in an electric circuit.

$$\text{Current (or Electric Flux)} = \frac{\text{Electromotive Force}}{\text{Resistance}}.$$

$$\text{Magnetic Flux} = \frac{\text{Magnetomotive Force}}{\text{Reluctance}}.$$

Therefore the

$$\text{Magnetomotive Force} = \text{Magnetic Flux} \times \text{Reluctance}.$$

As the resistance of an electric circuit can be expressed by the specific resistance or resistivity of the material multiplied by the length of circuit and divided by the cross section, so the reluctance of a magnetic circuit can be expressed by the specific reluctance or reluctivity of the material multiplied by the length of the circuit and divided by the cross section. Therefore the

$$\text{Reluctance} = \text{Reluctivity} \times \frac{\text{Length}}{\text{Area}}.$$

As the conductivity of an electric circuit is the reciprocal of the resistivity, so the permeability of a magnetic circuit is the reciprocal of the reluctivity. Therefore the

$$\text{Reluctance} = \frac{\text{Length}}{\text{Permeability} \times \text{Area}}.$$

or

$$\text{Magnetomotive Force} = \frac{\text{Magnetic Flux} \times \text{Length}}{\text{Permeability} \times \text{Area}}.$$

and since the magnetic flux divided by the area is the magnetic density the formula is simplified by writing

$$\text{Magnetomotive Force} = \frac{\text{Magnetic Density} \times \text{Length}}{\text{Permeability}}.$$

The Unit of Field Density, or the magnetic density caused by a unit pole, is 1 line of magnetic force per square centimeter of field area and is termed 1 gauss.

A single Line of Force, or the Unit of Magnetic Flux, is that amount of magnetism that passes through every square centimeter of cross section of a magnetic field whose density is unity, and is termed 1 weber.

The unit magnetic pole, or the pole of unit strength is that which repels an equal pole at unit distance with unit force. The lines of force are straight lines from the center of the sphere to the surface, there being one line to each square centimeter area on the surface. As the surface of a sphere having a radius of 1 centimeter has an area of 4π square centimeters, it follows that from a pole of unit strength there is a magnetic flux of 4π C. G. S. lines of magnetic force or 4π webers or 12.5664 webers.

One absolute C. G. S. unit of current, which is 10 times as large as the ampere, or 10 amperes, flowing in a wire 1 centimeter long bent into an arc of a circle of 1 centimeter radius gives a C. G. S. unit magnetic pole at the center of curvature or 12.5664 webers. One practical unit or 1 ampere would cause one tenth as many webers or 1.25664 webers.

A long solenoid having a cross section of one square centimeter having 1 ampere ($\frac{1}{10}$ of the C. G. S. unit current) flowing per unit length of coil, has poles of $\frac{1}{10}$ unit strength which causes a magnetic flux of $\frac{1}{10} \times 4\pi$ webers.

The density of the magnetic circuit is $\frac{4\pi}{10}$ webers per square centimeter or $\frac{4\pi}{10}$ gausses.

The reluctance of unit length of the solenoid of one square centimeter cross section for air is unity or 1 oersted. The magnetomotive force is the product of the magnetic density, the reluctance and the length, and is measured in gilberts. Therefore the magnetomotive force required to produce a magnetic density of $\frac{4\pi}{10}$ gausses in a column of air one centimeter long and having a cross section of one square centimeter thus having a reluctance of 1 oersted is

$$\text{M. M. F.} = \frac{4\pi}{10} \times 1 \times 1 = \frac{4\pi}{10} \text{ gilberts.}$$

The magnetomotive force of $\frac{4\pi}{10}$ gilberts being produced by one ampere-turn, it follows that the

$$\text{Number of Ampere-turns} = \frac{10}{4\pi} \times \text{Number of Gilberts.}$$

The

Magnetizing Force = Specific Magnetizing Force × Length, or the

Number of Ampere-turns = Ampere-turns per unit of Length × Length,

or $a\,t = f\,(\mathcal{B}'') \times l.$

where $a\,t$ = Ampere-turns required to magnetize a portion of a magnetic circuit;

$\mathcal{B}''$ = density of the magnetic circuit per square inch;

$f\,(\mathcal{B}'')$ = Specific magnetizing force, in ampere-turns per inch of length for the particular material and density employed; (this value of the magnetizing force must be taken from some table or induction curve as shown in Fig. 13, or found by experiment for the particular piece of iron to be used);

l = length of magnetic circuit of the material in inches.

To get the number of ampere-turns required to overcome the reluctance of the armature it is necessary to modify the above formula a little, as the value of $\mathcal{B}''$ is not constant in all parts of the core.

$$f\,(\mathcal{B}''_{a}) = \frac{1}{2}\left\{ f\,(\mathcal{B}''_{a1}) + f\,(\mathcal{B}''_{a2}) \right\}$$

$$= \frac{f\,(48{,}386) + f\,(34{,}291)}{2} = \frac{9.2 + 6.4}{2} = 7.8$$

It takes as seen from Fig. 13 about 9.2 ampere-turns to magnetize 1 inch of wrought iron to a density of 48,386 lines, and 6.4 ampere-turns to magnetize it to a density of 34,291 lines. Also 7.8 ampere-turns correspond to a density of **41,500 lines.**

8. Energy Losses in Armature, and Temperature Increase.

The energy lost in the armature due to the current in the armature conductors is

$$P_{a} = 1.2 \times (k_6 \times I)^2 \times r_{a}$$
$$= 1.2 \times (1.03 \times 200)^2 \times .0324 = \textbf{1650 watts.}$$

where P_a = energy dissipated in armature winding, in watts.
r_a = resistance of armature winding cold, in ohms ;
1.2 = ratio of resistance of armature winding hot, to resistance cold ;
I = output of machine in amperes ;
1.03 = ratio of total current generated to output.

The resistance of copper wire at 150° F. is about 1.2 times that at 60° F. The energy in the shunt coil of a 50 KW. compound dynamo is about 3 % of the output of the machine.

The loss in the armature core due to hysteresis is proportional to the 1.6th power of the magnetic density, directly proportional to the number of magnetic reversals, and directly proportional to the mass of the iron. Expressed in C. G. S. absolute units the energy consumed by hysteresis is,

$$P_h' = n_1 \times \mathcal{B}_a^{1\cdot6} \times N_1 \times M_1\,,$$

$$P_h' = n_1 \times \mathcal{B}_a^{1\cdot6} \times N_1 \times M_1',$$

where P'_h = energy lost due to hysteresis, in ergs;
n_1 = constant depending on magnetic hardness of material "Hysteresis Resistance ;
$\mathcal{B}_a$ = density of lines per square centimeter of iron ;
N_1 = frequency, or number of complete cyles of 2 reversals each, per second ;
M_1' = mass of iron in cubic centimeters.

For soft sheet iron discs n_1 may be taken as .0035. In order to get the value of P_h' in practical units we must change the above equation. One watt equals 10^7 ergs. Instead of $\mathcal{B}_a$ use the density $\mathcal{B}_a''$ in lines per square inch.

$$N_1 = \frac{N}{60} = \frac{1050}{60} = 17\tfrac{1}{2}.$$

One cubic foot equals 28,316 cubic centimeters. The mass of iron in the armature in cubic feet is

$$M = \frac{d_a''' \times \pi \times b_a \times l_a \times k_2}{1{,}728}$$

$$= \frac{(10.36 - 3.47) \times \pi \times 3.47 \times 24.75 \times .95}{1728} = 1.02 \text{ cubic ft.},$$

where M = net mass of iron, in cubic feet;
d_a''' = mean diameter of armature core, in inches,
= $d_a - b_a$, (see Fig. 17);
l_a = length of armature core, in inches;
b_a = radial depth of armature core, in inches;
k_2 = ratio of net iron section to total iron section.

There are 1,728 cubic inches in 1 cubic foot. Expressing the value of the energy lost by hysteresis in practical units we have,

$$P_h = 10^{-7} \times .0035 \times \left\{ \frac{\mathfrak{B}_a''}{6.45} \right\}^{1.6} \times 28{,}316 \times N_1 \times M,$$

where P_h = energy lost by hysteresis, in watts;
$\mathfrak{B}_a''$ = density, in lines per square inch, corresponding to average magnetizing force required for amature core, (1 square inch = 6.45 square centimeters);
N_1 = frequency, in cycles per second;
M = net mass of iron in amature, in cubic feet.

By reducing the above expression to simple form, we have

$$P_h = 5 \times 10^{-7} \times \mathfrak{B}_a''^{1.6} \times N_1 \times \mathrm{M},$$
$$= 5 \times 10^{-7} \times (41{,}500)^{1.6} \times 17\tfrac{1}{2} \times 1.02 = 219 \text{ watts.}$$

Eddy Currents.

It has been shown under *Electromagnetic Induction* (see theory of *Dynamo-Electric Machinery*, p. 4 et seq.) by what means and methods electromotive forces, and consequently electrical currents are set up in closed conductors. It is clear that any mass of metal moving in a field is a closed conductor. A loop of wire may have currents generated in it quite as easily if it be made part of a metallic disc as if it were still a loop. Since the lines of force can only cut a solid piece of metal once, the electromotive force that will be generated, unlike that in a coil of many turns cut by the same field will be very small. But if the piece of metal be large the resistance will be very small so that the current which is induced may reach considerable strength and cause much heating. This action is largely prevented from taking place in the armature cores of dynamos by building them up of thin sheets of iron. The sheets are insulated from each other and are placed in such a

direction as to cut across the path which would be followed by the induced current. This method of construction is termed lamination, and it is necessary to build all iron or metallic parts which are not intended to act as conductors, in this way, if they are likely to be subjected to fields of varying strength. This is the case in alternating current machinery and in the moving parts of direct current machinery. Sometimes even conductors if they are very large, have local currents generated in them which are of course undesirable because they are a source of waste and heat, and it becomes necessary to laminate them. In this case the lamination would be parallel to the length of the conductor. Heavy conductors are usually laminated or stranded any way, for greater ease in construction. Eddy currents are often called Foucault currents from Foucault who first called attention to their existence.

The energy lost by eddy currents is found to be proportional to the square of the magnetic density, to the square of the frequency, and to the mass. The equation for the lost energy due to eddy currents is,

$$P_e' = \epsilon' \times \mathcal{B}_a^2 \times N_1^2 \times M'_1 ;$$

where P_e' = lost energy due to eddy currents, in ergs;
$\mathcal{B}_a$ = density of lines of force, per square centimeter of iron;
N_1 = frequency, in cycles per second;
M_1' = mass of iron, in cubic centimeters;
ϵ' = eddy current constant, depending upon the thickness and the specific electric conductivity of the material;

$$\epsilon' = \frac{\pi^2}{6} \times \delta^2 \times \gamma \times 10^{-9}$$

$$= 1.645 \times \delta^2 \times \gamma \times 10^{-9}$$

where δ = thickness of sheet iron, in centimeters;
γ = electrical conductivity, in mhos;
γ = 100,000 for iron.

By changing to practical units and simplifying the above equation,

$$P_e = 10^{-7} \times 1.645 \times (2.54\,\delta_i)^2 \times 10^{-4} \times \left\{ \frac{\mathcal{B}_a''}{6.45} \right\}^2 \times N_1^2$$

$$\times\ 28{,}316 \times M = 7.22 \times 10^{-8} \times \delta_i^2 \times \mathcal{B}_a''^2 \times N_1^2 \times M.$$

where δ_i = thickness of iron laminæ in armature, in fractions of an inch;

$\mathcal{B}_a''$ = density, in lines per square inch, corresponding to average specific magnetizing force of armature core;

N_1 = frequency in cycles per second;

M = mass of iron, in cubic feet.

The terms 7.22, 10^{-8}, δ_i^2, and $\mathcal{B}_a''^2$, may be multiplied together to form the eddy current factor ϵ, and then the formula for loss due to eddy currents becomes,

$$P_e = \epsilon \times N_1^2 \times M$$
$$= .0125 \times (17\tfrac{1}{2})^2 \times 1.02 = 4.\ \text{watts.}$$

For ϵ = .0125 when the thickness of the sheet iron discs is .01″ and when the magnetic density is 41,500 lines.

The total energy loss in the armature is

$$P_A = P_a + P_h + P_e = 1650 + 219 + 4$$
$$= 1873 \text{ watts} = 2.5 \text{ h. p.}$$

Knowing the amount of electrical energy lost in the armature and dissipated as heat, and knowing the dimensions and speed of the armature it is possible to calculate quite exactly, by using certain known constants that have been found by experience, to calculate the rise of temperature in the armature and to calculate the hot resistance of the copper in the armature conductors. These details are somewhat complicated and will not be treated.

(*b*) Dimensions of Magnet Frame.

1. Total Magnetic Flux, and Sectional Area of Magnet Frame.

The total magnetic flux to be generated in a dynamo is the useful magnetic flux multiplied by a factor of magnetic leakage. Knowing the shape of the various parts of the magnetic circuit and the reluctance of the parts of the magnetic circuit and the sur-

rounding air circuits, it is possible to determine the amount of magnetic leakage, or waste magnetism.

$$\Phi' = \lambda \times \Phi = 1.35 \times 7{,}886{,}905 = 10{,}647{,}322 \text{ webers.}$$

where Φ' = total flux to be generated in dynamo, in lines of force;
Φ = useful flux necessary to produce the required E. M. F.
λ = factor of magnetic leakage, which for a 50 KW. bipolar machine of the Edison type is found to be about 1.35.

The sectional area of the magnet frame is expressed by the formula,

$$S''_{m} = \frac{\Phi'}{\mathfrak{B}''_{m}} = \frac{10{,}647{,}322}{90{,}000} = \textbf{118 square inches.}$$

where S''_{m} = cross section of wrought iron magnet core and of yoke, in square inches;
Φ' = total flux, in webers;
$\mathfrak{B}''_{m}$ = magnetic density of magnet frame, which for wrought iron magnet cores and yoke is taken as 90,000 lines per square inch.

The Practical Limit of Magnetization for cast iron pole pieces is taken as 50,000 lines per square inch.

$$S''_{m} = \frac{\Phi'}{\mathfrak{B}''_{m}} = \frac{10{,}647{,}322}{50{,}000} = \textbf{213 square inches.}$$

2. Sectional Area of Magnet Frame.

If the magnet core is in the form of a cylinder the diameter will be

$$d_{m} = \sqrt{\frac{4}{\pi} \times 118} = 12.25 \text{ inches.}$$

For a circular magnet core carrying about 10,000,000 lines of force the most economical ratio of length to diameter of magnet core is found to be about 1.5. Hence

$$l_{m} = 1.5 \times d_{m} = 18.375 \text{ inches.}$$

For a machine having an armature between 10 and 11 inches in diameter the distance, c, between magnet cores is taken as about

$$c = 5\tfrac{3}{4} \text{ inches.}$$

Take the width of the wrought iron yoke a little greater than

the diameter of the magnet cores so as to form a mechanical protection to them. Let this width be $18\frac{3}{4}$ inches. Then the height of the yoke would be

$$h_y = \frac{118}{18\frac{3}{4}} = 6\tfrac{1}{4} \text{ inches.}$$

The polepieces are determined as follows: — The bore of the polepieces is the sum of the diameter of the armature core, the winding, the insulation and binding, and the air gaps, which for a drum armature of this diameter is taken as about .14″.

$$\text{Diam. of bore} = 10.36'' + 4 \times .30922'' + 2 \times .11'' + .14'' = 11.96''.$$

In order to keep the corners of the polepieces far enough apart so that there will not be too much leakage across, the distance is taken from 1.25 to 8 times the length of the two air gaps according to the size and type of dynamo.

$$l'_p = k_{11} \times (d_p - d_a) = 4. \times (11.86 - 10.36) = 6.00 \text{ inches.}$$

where l'_p = distance between pole corners, in inches;
d_p = diameter of bore of polepieces, in inches;
d_a = diameter of iron core of armature, in inches;
k_{11} = 4. for drum armature of a 50 KW. bipolar dynamo.

Let the length of the pole pieces equal the length of iron core in armature, or

$$l_p = 24\tfrac{3}{4}''.$$

Let the height of polepieces equal the diameter of bore approx.

$$h_p = 12''.$$

The thickness at the center which carries only half the lines will be

$$\frac{213}{2 \times 24\frac{3}{4}} = 4.3 + \text{ or } 4\tfrac{3}{8}''.$$

In order to provide a non-magnetic base through which the magnetic lines will not leak from pole to pole a block of zinc about 5 inches thick should be placed under the dynamo.

(*c*) Calculation of Magnetizing Forces.

1. Air Gaps.

The length of the two air gaps is

$$l''_g = k_{12} \times (d_p - d_a) = 1.4 \times 1.5'' = 2.1''$$

where l''_g = length of path of magnetic lines across the two air gaps;

d_p = diameter of bore of pole pieces, in inches;

d_a = diameter of iron core of armature, in inches;

k_{12} = constant depending on the path of the lines of force through the air gap. The lines of force pass through the gaps obliquely owing to the distortion of the magnetic field and the constant, k_{12}, grows greater as the velocity of the conductor, v_c, and the density, $\mathcal{H}$, are greater. If the product of v_c and $\mathcal{H}$ is above 2,000,000 the value of k_{12} is taken as 1.4.

The cross section of the magnetic field of the air gap is represented by,

$$S_f = d_f \times \frac{\pi}{2} \times \beta'_1 \times l_f$$

$$= 11.11'' \times \frac{\pi}{2} \times .84 \times 24\tfrac{3}{4} = 363 \text{ square inches.}$$

where S_f = the area occupied by the effective conductors, in square inches;

d_f = mean diameter of magnetic field in inches;

$= \frac{1}{2}(d_a + d_p)$;

l_f = breadth of magnetic field, in inches;

β'_1 = ratio of effective field circumference, depending upon the percentage of polar embrace, here taken as .84.

The actual field density in air gaps is found by dividing the value of the total useful flux in webers, by the area of the magnetic field of air gap.

$$\mathcal{H}'' = \frac{\Phi}{S_f} = \frac{7{,}886{,}905}{363} = 21{,}727 \text{ lines per square inch.}$$

The number of ampere-turns required to produce this magnetic density in the air gaps is,

$$a\,t_g = \frac{10}{4\pi} \times \mathcal{H}'' \times \frac{l''_g}{2.54} = .3133 \times \mathcal{H}'' \times l''_g$$

$$= .3133 \times 21{,}727 \times 2.1 = \mathbf{14{,}295 \text{ ampere-turns.}}$$

2. Armature Core.

The average length of the magnetic paths in the armature is (see Fig. 18).

$$l''_a = d'''_a \times \pi \times \frac{90° + a}{360°} + b_a$$

$$= 6.89'' \times \pi \times \frac{90 + 28}{360} + 3.47'' = \textbf{10,57 inches.}$$

where l''_a = length of magnetic path in armature core, in inches;
d'''_a = mean diameter of armature core, in inches;
b_a = radial depth of armature core, in inches;
a = half angle between adjacent pole corners.

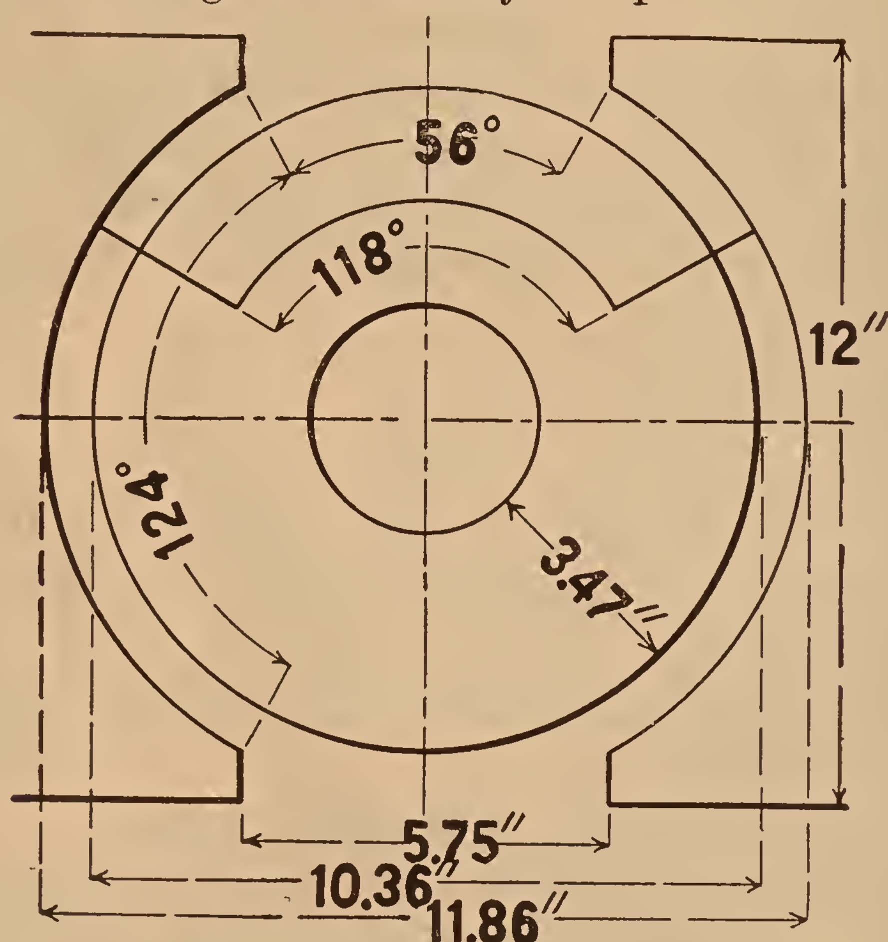

Fig. 18. Magnetic Details of Armature Core.

As previously determined the minimum cross section of the armature core is,

S''_{a1} = 163 square inches,

and the maximum cross section is

S''_{2a} = 230 square inches.

The average specific magnetizing force to magnetize the armature core to the required density will be

$$f(\mathfrak{B}''_a) = \frac{f\,(48{,}386) + f\,(34{,}291)}{2} = 7.8 \text{ ampere-turns.}$$

The total magnetizing force required to magnetize the armature is

$a\ t_a = 10.57 \times 7.8 =$ **82 ampere-turns.**

3. Wrought Iron Field Cores and Yoke.

The length of the magnetic path through the wrought iron cores and the yoke will be (see Fig. 14),

$l''_{w.i.} = 2 \times 18\frac{3}{4} + 6\frac{1}{4} + 18 =$ **61 inches.** (approx.)

The density of the field has already been decided upon as 90,000 lines per square inch. It has been determined by experiment that a specific density of 90,000 lines in wrought iron is produced by 50.7 ampere turns.

The total length of magnetic circuit through field cores and yoke will require

$a\ t_{w.i.} = 61 \times 50.7 =$ **3093 ampere-turns.**

4. Cast Iron Pole Pieces.

The average length of the magnetic path through the pole pieces may be taken as the average of the longest path and the shortest path. In the present case it is about

$l''_{c.i.} = 15$ inches.

The minimum cross section at the center of the pole piece which carries only half the lines has already been taken as

$S_{c.i.1} = 106.5$ square inches

which corresponds to a density of

$\mathfrak{B}''_{c.i.} = 50,000$ lines per square inch.

The maximum cross section of the magnetic circuit in pole pieces is the area of the pole face and is

$$S_{c.i.2} = 11.86 \times \pi \times \frac{124}{360} \times 24.75 = 318 \text{ square inches,}$$

which corresponds to a minimum density of

$$\mathfrak{B}''_{c.i.2} = \frac{7,886,905}{318} = 24802 \text{ magnetic lines.}$$

The average specific magnetizing force will be

$$f\,(\mathfrak{B}''_{c.i.}) = \tfrac{1}{2}\,[f\,(50,000) + f\,(24,802)] = \frac{160 + 38.6}{2}$$

$$= 99.3 \text{ ampere-turns,}$$

which corresponds to average density of 42,175 lines.

Then the total number of ampere-turns required to magnetize pole pieces is

$$a\,t_{c.i.} = 15 \times 99.3 = \textbf{1490 ampere turns.}$$

5. Armature Reactions.

The demagnetizing and cross-magnetizing effects caused by the ampere-turns of the armature oppose the magnetizing effect of the field coils and have to be overcome by adding more ampere-turns to those required to overcome the reluctance of the circuit.

* The number of ampere-turns required to balance the armature reaction is,

$$a\,t_r = k_{14} \times \frac{N_a \times I'}{2} \times \frac{k_{13} \times a}{180°}$$

$$= 1.71 \times \frac{96 \times 200}{2} \times \frac{28}{180} = \textbf{2554 ampere-turns.}$$

where $a\,t_r$ = ampere-turns required to compensate for armature reactions;

k_{14} = being a constant depending upon the magnetic density in pole pieces;

N_a = total number of turns on armature;

I' = total armature current in amperes.

2 = number of armature circuits for current;

$k_{13} \times a$ = angle of brush lead, which is nearly equal to half the angle between two pole corners, for smooth drum armatures.

† The total number of ampere-turns required on field coils of dynamo will be the sum of all the ampere-turns required for the various parts of the circuit.

$$AT = at_g + at_a + at_{w.i.} + at_{c.i.} + at_r$$
$$= 14{,}295 + 82 + 3093 + 1490 + 2554$$
$$= \textbf{21,514 ampere-turns.}$$

(*d*) Calculation of Magnet Winding.

The shunt winding should be calculated for a temperature increase of about 15°C above the normal temperature. (If desired

the shunt coil may be calculated so as to give a higher voltage to the dynamo which can be decreased by a regulating resistance in series with the shunt coil. As this calculation is not required in order to show the electromagnetic theory of the dynamo it will not be discussed here. It requires a recalculation of the magnetic flux for the various parts of the magnetic circuit and a recalculation of the corresponding ampere-turns.)

1. Magnet Winding.

The mean length of one turn of wire on the field core is

$$l_T = k_{17} \times d_m = 3.66 \times 12\tfrac{1}{4}'' = 44.8''$$

where k_{17} = a constant, depending upon the size of the field core, giving the ratio of the length of a mean turn to the core diameter.

The specific length of magnet shunt wire in feet per ohm is given by the formula,

$$\lambda_{sh} = \frac{L_{sh}}{r_{sh}}$$

$$= \frac{AT}{E} \times \frac{l_T}{12} \times (1 + .004 \times \theta_m)$$

$$= \frac{21{,}514}{250} \times \frac{44.8}{12} \times (1 + .004 \times 15)$$

$$= 340.5 \text{ feet per ohm.}$$

No. 15 B & S has 315 feet per ohm.

No. 14 B & S has 397 feet per ohm.

Use about No. 14 B & S wire.

The height of the winding space is given by the formula

$$h_m = \frac{l_T}{\pi} - d_m = \frac{44.8}{\pi} - 12.25 = 2 \text{ inches.}$$

The radiating surface of the magnet coils will be

$$S_M = (12.25 + 2 \times 2)\, \pi \times 2\, (18.375) = 1877 \text{ square inches.}$$

The energy absorbed in the magnet winding may be expressed by the formula,

$$P_{sh} = \frac{\theta_m}{75} \times S_M$$

$$= \frac{15}{75} \times 1877 = \mathbf{375\ watts.}$$

where P_{sh} = watts absorbed in field winding;

θ_m = rise of temperature in magnets, in degrees Centigrade;

S_M = radiating surface of magnet coils.

$$I_{sh} = \frac{P_{sh}}{E} \quad \text{or } I_{sh}\, E = P_{sh}.$$

Therefore the number of shunt turns may be found by

$$N_{sh} = \frac{A\ T}{I_{sh}} = \frac{A\ T \times E}{P_{sh}}$$

$$= \frac{21514 \times 250}{375} = \mathbf{14{,}343\ shunt\ turns.}$$

The length of the shunt winding is

$$L_{sh} = \frac{14{,}343 \times 44.8}{12} = \mathbf{53{,}547\ feet.}$$

The resistance of the shunt wire will be

$$r_{sh} = \frac{53{,}547}{340.5} = \mathbf{157\ ohms}, \text{ at } 15.5° \text{ C.}$$

The warm resistance at 30.5° C is

$$r_{sh} = 157 \times (1 + .004 \times 15) = \mathbf{166\ ohms.}$$

The shunt current at full load is

$$I_{sh} = \frac{250}{166} = \mathbf{1.5\ amperes.}$$

If desired it is a simple matter to get the weight of the wire used.

(*e*) Calculation of Efficiency.

The electrical efficiency of the dynamo is the ratio of the available energy to the available energy plus the energy lost due to armature resistance plus that due to field coil resistance.

$$\eta_e = \frac{P}{P + P_a + P_M}$$

$$= \frac{250 \times 200}{250 \times 200 + 1.06 \times 201.5^2 \times .0324 + 1.5^2 \times 166}$$

$= .96$ or **96% electrical efficiency.**

The commercial efficiency is the ratio of the output, to the sum of the output, wire loss in armature, wire loss in field, hysteresis loss, eddy current loss, and friction loss (which we will assume as 2,500 watts).

$$\eta_c = \frac{P}{P + P_a + P_M + P_h + P_e + P_o}$$

$$= \frac{50,000}{50,000 + 1,394 + 374 + 219 + 4 + 2,500}$$

$= .917$ or **91.7%, commercial efficiency,**

DESIGN OF

DIRECT CURRENT DYNAMOS.

EXAMINATION PAPER

American
School of Correspondence

BOSTON, MASS.,
U. S. A.

DESIGN OF

DIRECT CURRENT DYNAMOS.

Instructions to the Student. Place your name and full address at the head of the paper. Work out in full the examples and problems, showing each step in the work. Mark your answers plainly "Ans." Avoid crowding your work as it leads to errors and shows bad taste. Any cheap, light paper like the sample previously sent you may be used. After completing the work add and sign the following statement.

I hereby certify that the above work is entirely my own.

(Signed)

---

1. (*a*) What is the value of 9 horse-power expressed in watts? (*b*) In kilowatts? (1000 watts = 1 kilowatt).

2. (*a*) What is the value of 2400 watts expressed in horse-power? (*b*) What is the equivalent value of a 10 kilowatt dynamo expressed in horse-power?

3. (*a*) If a Phœnix arc light dynamo has an armature resistance of 3.448 ohms, and a series coil resistance of 4.541 ohms, what will be the lost voltage in the machine when a current of 10 amperes is flowing? (*b*) What will be the lost voltage when a current of 9.8 amperes is flowing? (*c*) What amount of energy in watts is lost in the armature for both of the above cases? (*d*) What amount is lost in the series field? (*e*) Express the total loss in horse-power in each case.

4. (*a*) If in a closed circuit the resistance between two points is 4.6 ohms what current must flow to cause a difference of potential of 20 volts? (*b*) If this current flows for 24 hours how many coulombs of electricity will have passed (from table page 4, 1 coulomb = quantity conveyed in 1 second by 1 ampere). (*c*) Also what energy in kilowatt-hours will be expended in the same time (1 kilowatt-hour equals the energy expended in one hour when the activity is one kilowatt).

5. (*a*) If a current of 100 amperes is transmitted a distance of 200 feet over No. 1 B. & S. copper wire, for how many volts should the dynamo be overcompounded in order to make good the lost voltage due to line resistance? (Refer to wire table, and note that to transmit a current 200 feet requires 400 feet of wire). (*b*) How much energy is lost in the line?

Ans. { (*a*) 5 volts approx.
(*b*) 500 volts approx.

6. (*a*) With 10 amperes flowing, with resistances as stated in question 3, and with $R = 300$ ohms what is the electrical efficiency of the dynamo? (*b*) What is the total horse-power generated by the armature? (*c*) What is the useful output of the machine in horse-power?

7. (*a*) If an arc lamp gives 2000 candle power at 50 volts and 10 amperes, how many candle power is furnished per horse-power in the case of arc lamps? (*b*) If a 16 candle power incandescent lamp requires 1.2 amperes at 50 volts how many candle power is furnished per horse-power in the case of incandescent lighting?

8. The resistance of three branches of an incandescent lighting circuit with all the lamps burning are 5 ohms, 16 ohms, and 12 ohms, what is their joint resistance, the three being in parallel?

9. Explain the reasons for over-compounding a dynamo.

10. Having the internal and external characteristic curves of a dynamo, how would you calculate the electrical efficiency?

11. (*a*) Give total resistance of circuit in which 12.5 amperes is flowing, the total E. M. F. developed being 100 volts? (*b*) If the external resistance is 10 times the internal, what is the external resistance in ohms? (*c*) The internal resistance? (*d*) What is the useful output of the dynamo? (*e*) What is the electrical efficiency?

12. If the resistance of the series coils of a dynamo is 10 ohms at 15° C. what will be the resistance after the temperature has risen to 35° C.?

13. (*a*) Explain the effect of the shunt coils of a compound dynamo. (*b*) Explain the effect of the series coils.

14. Explain quite fully the differences between a constant current dynamo and a constant potential dynamo.

15. (*a*) The total electromotive force of a series dynamo is 1000 volts, and the resistance of the armature and series coils is 40 ohms. If a current of 10 amperes is flowing what will be the resistance of the external circuit? (*b*) What will be the electrical efficiency of the dynamo? (*c*) What will be the total horse-power generated by the armature?

16. (*a*) If the external E. M. F. of a dynamo is 550 volts and 10% of this voltage is lost in transmitting a current of 580 amperes a distance of one-half mile (one mile of wire required) what is the resistance of the conductors? (*b*) What is the resistance per foot of conductor? (*c*) About what size of copper wire would be required?

17. (*a*) If a ring-wound or drum-wound armature of a bipolar ordinary compound-wound dynamo has 200 complete turns of copper conductor, if the total magnetic flux cut by these conductors is 12,000,000 magnetic lines of force, and if the armature runs at 1500 revolutions per minute, what is the total E. M. F. in volts generated in the armature? (*b*) If at full load the lost voltage in the armature is $2\frac{1}{2}\%$ and the value of r_{sh} is 500 ohms, what current flows through the shunt field coils? (*c*) If $2\frac{1}{2}\%$ of the energy generated is lost in the armature, 2% in the field coils, and $1\frac{1}{2}\%$ in the series coils, what is the electrical efficiency of the dynamo? (*d*) What is the total output in kilowatts?

18. (*a*) In the following equation explain the meaning of each of the symbols used

$$\eta_e = \frac{1}{1 + \frac{R\,(r_{sh} + r_a)}{r^2_{sh}} + \frac{r_a}{R} + 2\,\frac{r_a}{r_{sh}}}$$

(*b*) For what type of dynamo does this equation give the electrical efficiency?

19. (*a*) By what means can the electrical efficiency of a dynamo be increased? (*b*) In order that a shunt dynamo shall have an efficiency of 95% what is the value of $\frac{r_{sh}}{r_a}$? (*c*) Are there any objections to having the value of $\frac{r_{sh}}{r_a}$ as great as 100,-000 for small dynamos? (*d*) If the electrical efficiency of a 5000 horse-power dynamo is 98% how much electrical energy is lost, expresed in kilowatts.

20. (*a*) Explain the meaning of the *Electrical Efficiency* of a dynamo. (*b*) Explain the meaning of the *Commercial Efficiency* of a dynamo. (*c*) What is a *Saturation Curve?* (*d*) What is an *External Characteristic?* (*e*) *Internal Characteristic?* (*f*) How would you construct a horse-power curve?

‡ 21. Draw as nearly as you can the shape of the internal and external characteristic curves of a shunt dynamo of about 5 horse-power, beginning with an initial E. M. F. of 115 volts. Draw the necessary horse-power curves. (Make ordinates 20 volts per inch, and abscissae 10 amperes per inch.)

22. Draw as nearly as you can internal and external characteristic curves for a series dynamo, the maximum energy to be about 10 horse-power. (Make ordinates 100 volts per inch, and abscissae 5 amperes per inch.)

23. Draw as nearly as you can internal and external characteristic curves of a compound dynamo, the maximum energy to be about 8 horse-power, and initial voltage to be 120. (Scale as in question 21.)

24. Plot the curve of electrical efficiency for the Wood dynamo (see data page 25). (Make ordinates 20% per inch, and abscissae 2 amperes per inch.)

25. (*a*) Form a resistance scale on the plot for the series dynamo in answer to question 22. (*b*) What was the resistance of the external circuit when the maximum current was flowing? (*c*) What was the total resistance of the circuit?

‡In answering this and following questions requiring plots, the student should use sheets of co-ordinate paper, size about 6 inches by 9 inches, the smallest divisions being .1 inch with lines every inch apart made heavy. The student may draw these neatly himself, or will be supplied by the school upon request.

26. (*a*) What is the value of the maximum horse-power indicated on Fig 12? (*b*) What was the resistance of the circuit at that point?

27. If the field coils of a shunt dynamo have a resistance of 600 ohms and the voltage at the brushes is kept constant at 520 volts, how much energy expressed in watts is lost in the field coils?

28. (*a*) A compound dynamo running at no load has an E. M. F. of 112 volts. At full load the E. M. F. at the brushes is 120 volts. For what percentage is the dynamo overcompounded? (*b*) If 50 horse-power is required to drive the armature of a dynamo which is delivering 33,000 watts to the external circuit, what is the commercial efficiency at this load? (*c*) If 35,000 watts are delivered to the outside circuit of a dynamo which requires 39,000 watts to run it, what percentage of the energy is lost? (*d*) If a dynamo that is delivering 40,000 watts has a commercial efficiency of 93%, how much energy expressed in horse-power is required to run the armature?

29. What becomes of the energy lost in a dynamo, that is, the energy that represents the difference between the input and the output of a dynamo?

30. A shunt-wound dynamo is to run at a constant E. M. F. of 180 volts. At this voltage and at no load the regulating rheostat which is in series with the shunt coils has all of its resistance in and the current flowing is 1.5 amperes. At full load a current of 1.8 amperes is necessary to magnetize the field coils in order that the full voltage should be maintained. (*a*) How many ohms resistance must be cut out of the rheostat? (*b*) An ordinary compound dynamo with an initial E. M. F. of 500 volts is overcompounded for 5 % at full load. At full load the current in the shunt field coils is 5 amperes. On account of excessive loss of voltage in the distributing mains it is desired at full load to increase the E. M. F. at the brushes to 550 volts. In order to do this a current of 5.5 amperes must flow through the shunt field coils. How much resistance must be cut out of the regulating rheostat in series with the shunt field coils in order that the voltage shall be raised to 550? Ans. 5 ohms.